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A  
TREATISE  
ON  
PERFECT RAILWAY SIGNALING

DESCRIBING THE DEVELOPMENT OF THE ELECTRIC  
TELEGRAPH AND BLOCK SIGNALING SYSTEMS

THEIR DAMAGE AND DERANGEMENT DURING  
THUNDERSTORMS

AND EXPLAINING THE REQUIREMENTS FOR  
RELIABLE SIGNALING

BY  
HENRY W. SPANG

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ILLUSTRATED

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1902

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## PREFACE.

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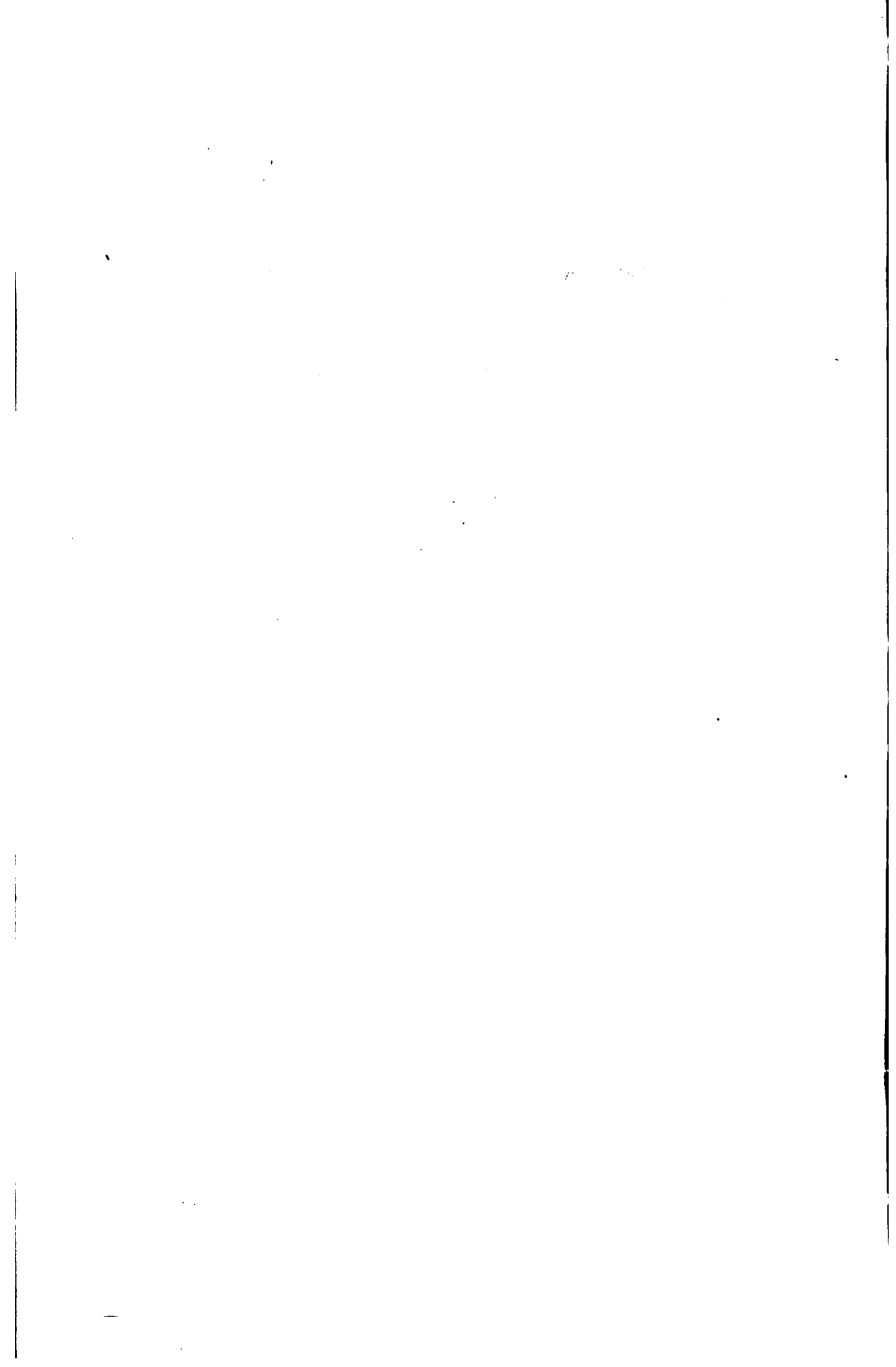
THIS work is the outcome of years of observation and investigation made by me of the paths selected and effects produced by lightning discharges, from which the proper requirements for effecting absolute protection of electrical circuits, etc., have been determined. The frequent impairment during thunderstorms of electric signaling and other circuits along railroads is well known among railroad men, who recognize the necessity of a proper solution of the lightning protection feature before perfection can be attained in railway signaling.

Special attention has been given to the effects produced upon the automatic block systems using the track circuit, and proper improvements have been developed which will not only eliminate the annoying lightning effects attending such systems, but also greatly increase the reliability and efficiency of the track circuit for signaling purposes.

It will be observed that considerable space is devoted to a description of all the phenomena attending lightning discharges. This has been done for the reason that correct information thereon is greatly desired by railway men, who recognize its important bearing upon railway signaling.

HENRY W. SPANG.

NEW YORK, November, 1902.

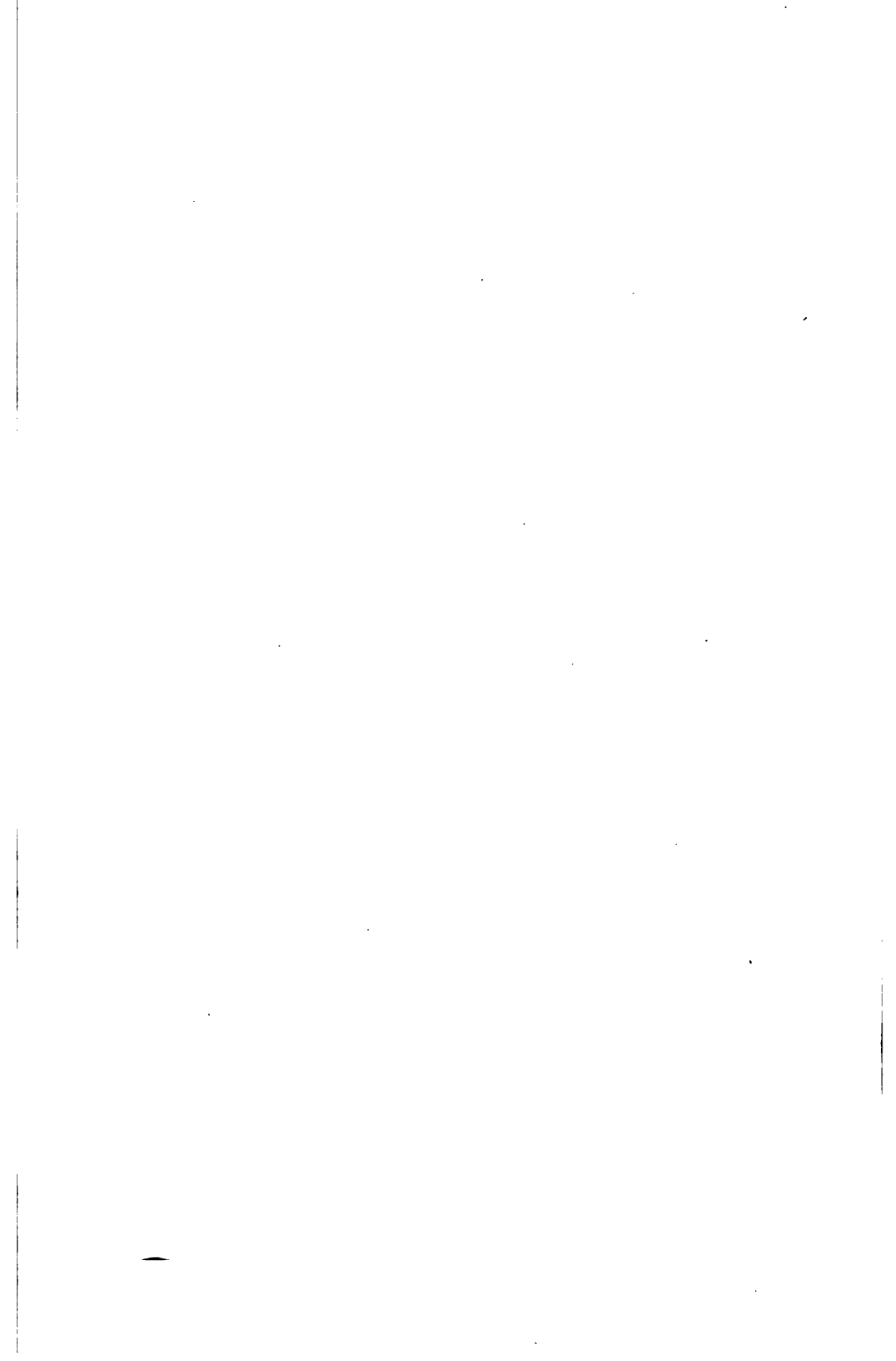




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# PERFECT RAILWAY SIGNALING.

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## Introduction.

**I**T is a well established fact that electricity must be employed to facilitate the movement and secure the safety of railway traffic, and there is no branch of the electrical science in which simplicity, reliability and accuracy are more essential than with automatic and other railway signaling.

Our aim has been to overcome certain objectionable features which have been and are still inherent in all such systems, and thereby secure perfection, as far as is possible with human ingenuity.

From the first introduction, every electric railway signaling system has been subjected to derangement during thunderstorms, giving rise to improper signals, causing collisions and delay of traffic.

Quite a number of systems with ingenious devices have been tried only to be quickly discarded owing to the disastrous effects of such disturbances. With the employment of the rails as electric conductors for automatic signaling purposes, the annoying effects of induced electricity during thunderstorms have greatly increased.

The true actions of lightning discharges and the proper requirements for effecting absolute protection therefrom are comparatively unknown.

In view of the great importance of the subject and the amount of nonsense that has been promulgated thereon, the author has deemed it advisable to fully treat it in all its phases and to present such an array of indisputable facts, that even the layman can properly understand all the phenomena of lightning discharges.

The brief review of electrical progress and the development of the electric telegraph and railway signaling is given for the purpose of showing that the rapid advances made in the electrical science in the last century, have been confined solely to such research as could be determined in the laboratory; while in the matter of the lightning discharge and protection therefrom, which have required an investigation of natural phenomena, not to be obtained in a laboratory, no important discovery or improvement has been made since the days of Franklin.

The author was one of the pioneers in the use of the rails as electric conductors for automatic railway signaling purposes, and has given the subject careful consideration throughout the past thirty years.

Improved automatic signaling systems are forthcoming in which the disastrous effects of atmospheric electrical disturbances are overcome, and an engineer is enabled to determine when an improper signal is given through defective mechanism or other cause. This is also an essential feature of safe signaling.

The systems are simple and reliable. They can also be applied to any railway now using a rail circuit system.

The work is issued as a preliminary step toward effecting the general introduction of these improved systems.

### What is Electricity?

The only answer that can be given with certainty is that it is one of the great forces of nature pervading the air, earth and all matter, and is as all-prevailing in its effects as are light and heat. We are cognizant of its existence, but we do not know its particular form any more than we know that of sound or light.

We know it from its effects and through its relation with other forces.

We do not make electricity. We only convert other forces into it. It is produced by, and itself produces, magnetism. It produces and is produced by heat, by mechanical and by chemical force.

Electrical science has disclosed the intimate relation existing between light, heat and electricity, and has led us to a better comprehension of nature. We now know that they are manifestations of wave motion and differ only in length of waves.

Sir Isaac Newton by his assumption of the necessity for some existing thing across which the influence of the sun and other heavenly bodies could be transmitted to us, called into being the ether,—that tenuous something that fills all space and permeates all matter and which transmits to the earth the heat and light of the sun, and which is also undoubtedly the primal source of electricity, or of the radiant energy, which gives us light, heat and electricity.

Recent researches are pointing the way to an understanding of the connection between gravitation and electricity and the unification of all forces of nature.

From many observations and investigations made in the northern regions it has been discovered that the *aurora borealis* is the result of the electrification of strata of air at varying heights above the sur-

face of the earth. Quiet auroras are the highest; unsteady ones are quite low; but none touches the ground. Simultaneous with the appearance of sun-spots as announced by astronomers, there is invariably a great display of auroras, accompanied by a generation of earth currents and magnetic storms. Even the terrific thunderstorms which intensely electrify the surface earth with a vivid light, and are attended with a great destruction of life and property seem to be coincident with outbursts of solar activity.

During 1872 there were great and numerous displays of auroras and some of the most terrific thunderstorms occurred in this country and Europe during that year. In New York and the New England States alone during August 14, 15 and 16, 1872, over 200 dwellings were struck, ignited or otherwise damaged; 10 persons were killed and 160 injured; a large number of barns were ignited and with them hay, horses and cattle consumed. Railway trains, while running, were surrounded by a vivid light. Telegraph wires were melted by the half mile, instruments destroyed, and poles shattered in all directions.

With the announcement by the astronomer at Greenwich, England, November 17, 1882, of the appearance of an enormous sun spot, not a wire of the Western Union Telegraph Company could be used for three hours on the morning of that day. At night there was a brilliant auroral display, and the entire telegraph service in this country, including the cable to England, could not be worked.

Cases can also be cited where powerful earth currents have prevailed in some localities, a brilliant aurora at another, and thunderstorms at yet other places, upon the same day, and many miles apart, all undoubtedly being the effects of solar influence.

### **Electrical Actions and Properties.**

A thorough knowledge of the effects which electricity is capable of producing under different conditions and the laws which govern its actions, are all the requirements needed by the practical electrician.

Two kinds of electrical force are now recognized, which are distinguished by the terms *positive* and *negative*. They are respectively indicated by the algebraic signs + (plus) and — (minus).

In the natural state of a body every portion contains the same amount of each of the two electrical forces, thereby forming an equilibrium between them, and they are then said to be *neutral*, or inactive.

The electrical equilibrium of a body may be disturbed by friction,

chemical action, changes of temperature, and other causes; and then the two electrical forces will be separated, the positive accumulating in one portion of the body, and the negative in another, and in such case electrical action is exhibited, and the body is then said to be *electrified*, or charged with electricity.

When a body, or part thereof, contains all positive, or more positive than negative electricity, it is said to be positively electrified or charged; and when it contains all negative, or more negative than positive, it is said to be negatively electrified or charged.

When the two opposite electricities are accumulated on bodies separated from each other, and are in a state of rest, they are said to be in a *static* state; and when they rush toward each other, to restore the equilibrium between them, they are said to be in a *dynamic* state.

Bodies charged with the same kind of electricity repel each other, but when charged with opposite electricities, there is mutual attraction and disposition to unite and form an equilibrium between them. This is the fundamental law of electric action.

When a body is electrified, positively or negatively, and is brought within a suitable distance of another body, and particularly one of good conductivity, and the latter is in its natural or neutral state, the electricity of the former will, by a peculiar influence, cause the two electricities of the latter to be separated, repelling the electricity of the same phase, and attracting that of the opposite phase.

This peculiar influence is known as *electric induction*, and bodies in this state are said to be electrified or charged *by influence*.

According to Faraday, "it is of the most general influence in electrical phenomena, appearing to be concerned in every one of them, and has in reality the character of a first, essential, and fundamental principle."

"It appears to be essentially an action of contiguous particles, through the intermediation of which the electric force, originating or appearing at a certain place, is propagated to or sustained at a distance, appearing there as a force of the same kind, exactly equal in amount, but opposite in its direction and tendencies."

The term *dielectric* is applied to the substance or medium through and across which electric inductive action occurs.

Faraday, having proved that electric induction always has a dielectric, supposes the particles or molecules of the dielectric to be conductors, insulated from each other.

When an insulated body is positively electrified and is brought near another that is negatively electrified, a rushing together of the opposite electricities takes place and a spark is produced over the air gap, which is known as a *discharge*.

When the electricity generated by a voltaic battery or dynamo flows over a wire or other good conductor, it is termed a *current* and the path over which it flows is known as the *circuit*. A *direct or continuous* current flows in one and the same direction, while the *alternating* current flows alternately in opposite directions.

*Quantity* is the term applied to the amount of electricity present and *ampere* is its unit of measurement. *Potential* (sometimes known as pressure or tension) implies that function which determines its motion from one point to another and *difference of potential* is the term employed to denote that portion of electromotive force which acts between any two points in a circuit.

*Resistance* is the term applied to the opposition or obstacle opposed to the passage of electricity by the substance or body through which it passes. It is the inherent property of every substance. The various metals offer a low resistance and permit electricity to flow freely through or over them, and are termed *conductors*, while stone, brick, wood, dry earth, glass, gutta-percha, mica, etc., offer a high resistance to it, and retard its flow, and are termed *non-conductors* or *insulators*. *Ohm* is the unit of its measurement. The *Volt* is the electric force which maintains a current of one ampere in a conductor whose resistance is one standard ohm.

Electricity manifested by different means is characterized by different properties. The electricity manifested by ordinary friction has a high potential, and is able to readily overcome the resistance of poor conductors, but its quantity is small, and it therefore produces weak magnetic and mechanical effects.

On the other hand, the potential of the electricity manifested by the chemical action in a galvanic cell or battery is low, and cannot overcome great resistance, but its quantity is medium and is capable of producing practical magnetic and mechanical effects.

The potential and quantity of electricity generated by a dynamo varies according to the purposes for which it is employed.

There is an erroneous impression that the electricity of a lightning discharge has small quantity; but it should be quite apparent to any electrician that its great heating and illuminating effect, and the melting of long lengths of telegraph, telephone and fence wires or other metal masses could be accomplished only by enormous quantity or amperage.

Furthermore, when we consider the great length of such discharges, varying from 500 to 25,000 feet, shattering great thicknesses of solid rock, and demolishing high stone and brick spires and high stone monuments it is quite evident that their potential is also enormous and beyond calculation and that there is no such thing as a non-

conductor as far as they are concerned. Their destructive effects are manifested when they are obliged to flow over substances, offering a certain resistance, such as stone, brick, slate, wood, hay, grain, tobacco, ice, cotton, feathers and other non-metallic substances, and even upon metallic substances under certain unfavorable conditions, to which reference will be made in this work.

All galvanometer or other electrical measurements are worthless, so far as relates to the determination of ground connection and other lightning protection requirements. In fact the lightning discharge constitutes a distinct feature of the electrical science and must not be treated according to the phenomena or requirements of artificial electricity.

### Electrical Progress.

The lightning discharge was, undoubtedly, the first electrical phenomenon observed by mankind; but all its actions have only been recently determined.

Among the phenomena observed by the ancients is the great attraction of lightning discharges for oak and similar trees that have great out-spreading branches. To this, reference was made by Greek writers over twenty-two hundred years ago. Similar phenomena have also been observed in every age. They puzzle even our present scientists.

In fact the progress made in the electrical science has been confined principally to such research as could be determined in the laboratory; while in the matter of the lightning discharge and proper protection therefrom, the necessary requirements are still comparatively unknown.

About 600 years before the Christian era, Thales, the founder of Ionic philosophy, observed that when amber was subjected to friction, it acquired the power of attracting light substances, such as small pieces of feathers. This action is the germ out of which has grown the electrical science. Until 1600 not another fact respecting electricity was known. Then Dr. William Gilbert of Colchester, England, issued his work "De Magnete." He was the first to recognize electricity as a natural force or condition and to study the subject. He derived its name from *elektron*, the Greek word for *amber*. He also proved that the compass needle was controlled by the earth itself, acting as a great magnet, and filling the surrounding space with an invisible agency.

Otto Von Guericke of Magdeburg, in 1671, invented the first frictional electrical machine. It consisted of a revolving ball of sulphur, (afterwards replaced by a sphere of glass); a cylinder of glass.



Finally in 1760, the circular plate glass that is still used, was employed. In 1745 Von Kleist, Dean of the Cathedral of Camin in Pomerania, experienced a shock after the water in a bottle had been charged by a frictional electric machine; and in the following year Muschenbroeck, Professor in the University of Leyden, observed that it was only the person who held the bottle in his hand that felt the shock, a condition Von Kleist failed to recognize; and hence it derived the name of the Leyden jar.

The famous frictional electrical experiments by Franklin were made during the three years, 1747-9.

He suggested the lightning rod in 1750, and made the celebrated kite experiment in 1752, by which he established the similarity between lightning and electrical sparks.

The slow progress made in the electrical science up to this time was principally due to the fact that natural philosophy in every age has been opposed by superstition and a blind and immoderate zeal for religion. Even in the eighteenth century, the lightning rod was denounced as heretical. Luigi Galvani, medical lecturer at the University of Bologna, after the publication in 1791 of his electrical researches, which finally led to the invention of the voltaic pile in 1799 by Alessandro Volta, of the University of Pavia, was deprived of his position and titles, reduced to poverty and died broken hearted.

It was not until Volta's discovery that two different metals immersed in a solution would generate an electric current, that electricity could take its place as an agent of practical value.

Prior thereto there was no application of electricity to any useful purpose. The numerous experiments with frictional electricity made clear the principles of attraction and repulsion, conduction and insulation, and served to distinguish the two opposite conditions, known as positive and negative.

The nineteenth century will ever be remembered for the rapid progress made in the electrical science, dating from Oersted's discovery in 1820, which is the starting point of the electric telegraph and dynamo. Following the exhibition of the telephone at the Centennial Exposition in Philadelphia in 1876, came the rapid development of the arc and incandescent systems of electric lighting, electric motor and traction, electric welding, wireless telegraphy, and other important electrical inventions.

### **Development of the Electric Telegraph.**

Like all other inventions the electro-magnetic telegraph has not been the product of a single mind. It was, in fact, a growth and involved the invention of many able men.

Among those who had observed the phenomena of voltaic electricity was Hans Christian Oersted, a professor of physics in the University of Copenhagen.

He announced on July 21, 1820, that a voltaic current passing through a wire placed horizontally above and parallel to an ordinary compass needle, caused it to sway on its axis to the east or west, according to the direction of the current. There is hardly a parallel instance in the history of electricity of a discovery so soon turned to practical account.

During the same year, Francois Arago, a French scientist, announced that a piece of iron in a glass tube surrounded by a spiral wire through which a current flowed became magnetic.

From this fact, Ampere, another French scientist, determined the relations between magnetism and electricity and also showed that wires bearing currents attract or repel each other, just as magnets do.

Schweigger, of Halle, discovered that the deflecting power of a current was multiplied by means of an insulated wire of many turns wound around the needle instead of the single wire used by Oersted. He thus constructed the first galvanometer, an instrument used for electrical measurement.

In 1825 William Sturgeon of Woolwich, England, following Arago's discovery constructed an electro magnet consisting of a piece of iron in the form of a horse shoe with its surface coated with varnish and surrounded by a single coil of plain copper wire. The magnetic excitation was feeble.

In 1827 Dr. G. S. Ohm of Nuremburg, Germany, formulated the law governing electric action; which is, that the current strength of a circuit is equal to the electro-motive force divided by the resistance.

While professor of mathematics and natural philosophy of the Albany Academy, Joseph Henry in researches conducted from 1828 to 1830 greatly improved Sturgeon's device by applying thereto wire coils, following Schweigger's winding.

He was the first person to form a clear conception of the difference between *intensity* and *quantity* both in the battery and electro-magnet.

To him belongs the exclusive credit for having first constructed the intensity wire coils or bobbins now employed with the electro-magnetic telegraph and signaling systems.

It is said he spent months in wrapping wire with cast off gowns to insulate it for his experimental electro-magnets.

While professor of natural philosophy at Princeton College he

experimented in 1836 with devices embodying the principle of the relay magnet and local circuit, which also greatly aided in paving the way for the complete system of telegraphy.

S. F. B. Morse, an artist of repute, on a voyage from Havre to New York in the packet Sully in 1832 conceived the idea of applying chemical decomposition by the electric current for telegraph purposes and in 1835 constructed a crude experimental model thereof. He had but little mechanical skill and but limited means to properly carry out his idea.

In 1837 Alfred Vail became his partner in the enterprise, and in that year the latter not only designed the recording telegraph register, capable of making dots, dashes and spaces, but also prepared the code of alphabetical signs now used in telegraphy.

In England during 1836 Grove invented the nitric acid battery and Daniell the sulphate of copper and zinc battery, with the electrodes separated by a porous cell. The latter battery is capable of yielding an approximately constant current for a prolonged period, and is therefore best adapted for telegraph and similar purposes. The gravity modification thereof was suggested by C. F. Varley in 1854.

### **The Earth as an Electric Conductor.**

The celebrated German astronomer, L. F. Gauss, who was, with his coadjutor, W. F. Weber, the founder of our modern system of absolute measurements of physical forces, and who also originated the methods of more or less continuous observation of the earth's magnetic changes, by hourly or more frequent observations, in 1833 erected a telegraph line between the Observatory of Gottingen and the Physical Cabinet, about six thousand feet in length, and employed a galvanometer or needle system therewith.

It was used for determining the action of a current through a conductor of such length and for lack of time, Prof. C. A. Steinheil of Munich, was requested by Gauss to complete the telegraph system, and the degree of perfection to which it was brought by the latter was such that it may be regarded as a distinct invention.

In 1837 Steinheil erected a telegraph line from the Royal Academy, in Munich, to the Observatory at Bogenhausen, a distance of about three miles.

It was a complete metallic circuit and during 1838, while making some experiments on the Nurnberg-Further Railroad, for the purpose of determining whether the track could be used for telegraphic purposes, he noticed that the current passed from one of the rails to the other through the earth, and the thought occurred to him whether

it might not be possible to use the ground itself, and in this way dispense with half of the metallic circuit. This proved to be feasible, and he was thus enabled thereafter to work his line with a single wire.

The discovery by Steinheil that the earth may serve as a conductor for the galvanic current is justly regarded as one of the most important in the art of electric telegraphy ever made. It is one which has contributed very largely toward the extensive development of telegraphic lines.

In 1747, Dr. William Watson in London, sent frictional electrical charges through wires 2,800 and 10,060 feet long, in connection with the earth.

About the same time Franklin made a similar experiment, by an overhead wire across the Schuylkill River at Philadelphia, but the importance of this feature of the electrical science was not then recognized. In fact, its great importance has not received the consideration that it merits, and the requirements necessary for its proper and most efficient use for the different artificial electrical currents are unknown.

### **American Railway Telegraphs.**

After a series of discouragements that would have disheartened most men, Morse, assisted by Vail, established in 1844 the first telegraph line in this country, between Washington and Baltimore. Congress, after a prolonged struggle, made in 1843, an appropriation of \$30,000 therefor.

The first railroad in this country which provided itself with a telegraph line devoted exclusively to the business of the road was the New York & Erie. A single wire was installed about 1850, between Piermont and Dunkirk. This was at first employed merely for the transmission of communications to and from officers, employees, etc. The idea of its being practicable or safe to employ it for the movement of trains does not seem to have originally occurred to any of the officers of the road.

Upon one occasion, during 1851, Mr. Luther G. Tillotson, then Superintendent of the telegraph line, together with the Division Superintendent of the railroad, while at Elmira tried with success the experiment of facilitating the movement of a stock train which had been lying at Corning for some time waiting for a distant express train. It was no uncommon occurrence for freight trains in those days to lie at stations for hours and days waiting for belated passenger trains. The system of train dispatching by telegraph was first adopted on the Susquehanna Division of the Erie Railroad, but only after the most strenuous efforts were made to prevent its introduction,

not only by nearly all the officers of the road but by the conductors and engineers, some of whom went so far as to sacrifice their situations rather than submit to such an innovation, as that of running against the time of another train, on a telegraphic order.

The system once established upon the Erie Railroad gradually extended to the principal railroads of this country.

The amount of time and money saved to the American railroads by the use of this system is almost incalculable, when their great tonnage is considered.

In 1829 the first locomotive in this country was tested upon a little wooden track road along the Lackawaxen Creek in Pennsylvania, and since then the railway systems of the United States have grown to such an extent, that if straightened out, they would make a single track extending eight times around the world. They carry more tonnage than all the ships on all the seas, together with the railroads of the busiest half of Europe.

Railroads and telegraphs are the sinews and nerves of national life and the principal agencies in welding the widely separated States and Territories of this country.

The total railroad mileage of the world is about 500,000, of which the United States has about 200,000; Germany, 32,000; Russia, 29,000; France, 27,000; Austria-Hungary, 23,000; Great Britain and Ireland, 22,000, while no other European country exceeds 10,000 miles.

### **Atmospheric Disturbance of Telegraph and Signaling Circuits.**

Since their first introduction, telegraph lines, railway signaling and, in fact, all such electrical circuits have been subjected to considerable disturbance and damage during thunder-storms, when such overhead, surface and underground circuits, and especially those of great length, became intensely electrified by the inductive influence of highly charged clouds. This disturbance extends over a greater distance, upon circuits running east and west, or parallel with a storm than upon those running north and south, and the induced electrification is greater upon circuits connected with the earth,—(as ordinary grounded telegraph lines, overhead trolley railways, also track circuits and long signal circuits under their control)—than upon wholly metallic circuits, insulated from the earth and especially those distant from railways and underground pipes.

The atmospheric phenomena are as follows:

1. A terrific lightning discharge in a somewhat concentrated form, usually between a high cloud and a body of water, or an iso-



W. N. Jennings.

*Fig. 1. Lightning Discharge About Three Miles Long, Philadelphia.*

lated object upon the earth, and especially in line with an underground water or gas main, railway tracks, wire fences, and overhead and underground electrical circuits; the discharge being attended usually with great destruction.

2. A lightning discharge in its greatly diffused form usually in connection with a low cloud and great rainfall and by numerous ramifications in line with a forest, or a number of buildings or objects, especially those located in the rural districts, where there are no long metallic conductors.

3. Small discharges which take place in connection with electrical circuits, simultaneously with a concentrated or diffusive lightning discharge and especially when taking place between the clouds and the earth within a distance of about three miles of an electrical circuit.

These are erroneously known as static or lateral discharges and are usually attended with derangement of such circuits.

4. Less intense discharges upon electrical circuits which take place simultaneous with more distant discharges between the clouds and the earth, or between two clouds or layers thereof.

5. Small discharges upon electrical circuits arising from a greatly increased air potential and without a lightning discharge, sometimes produced by high wind, and especially in connection with sand, dust and snow storms, escaping steam from a locomotive, etc., or induced thereon by powerful electrical currents upon adjacent electric light or other similar lines.

They are usually known as sneak currents and are sometimes of sufficient intensity to fuse the fine wires of telephone, telegraph and other similar apparatus.

When a lightning discharge or a main branch thereof takes place in direct line with a telegraph, telephone or other electric circuit, it is invariably attended with destructive effects; such as shattering many wooden poles, impairment of insulators, melting of wires, destruction of electrical apparatus, ignition of telegraph and telephone offices and railroad depots, signal towers and other buildings into which they enter, and especially those in the rural districts; also the death and injury of telegraph operators, signalmen and house inmates in such districts.

That such direct discharges with electrical circuits are annually increasing and attended with destruction or damage, especially in the rural districts, is quite evident, judging by the annual increased number of such fires during the past twelve years, and also by the fact that there are more suits pending at present for death and injury of persons in buildings by lightning discharges in connection with telephone and other wires than during any previous time.



Wm. Archibald.

*Fig. 2. Multiple Discharge From Low Cloud. Newark, N. J., Meadows.*

The small discharges are the most frequent manifestations upon electrical circuits during thunderstorms and cause interruptions thereof and impairment of the electrical apparatus.

Trains are usually delayed during and after thunderstorms, owing to damage to road-bed by heavy rainfalls. Consequently there is no time when the use of the telegraph and signaling systems is more urgently needed for properly and safely handling trains than during and after such a storm.

Notwithstanding the present protective devices, railway telegraph lines and the different railway signaling circuits are impaired during thunderstorms, thereby suspending proper train dispatching and signaling until the electric circuits and apparatus are repaired.

All atmospheric electrical actions and phenomena during thunderstorms are fully explained so that every electrician and railway manager can properly comprehend the subject and understand why the proper requirements for properly protecting electrical circuits have been generally unknown.

### **Observations of Franklin.**

The celebrated American philosopher, Benjamin Franklin, while on a visit in 1746 to Boston, his native town, witnessed and became



greatly interested in electrical experiments made by a Dr. Spence with a three foot glass rod rubbed with a silk handkerchief.

It so happened that shortly after his return to Philadelphia Mr. Peter Collinson, the London agent for the Library Company of Philadelphia, who was accustomed to send with the annual parcel of books any work or curious object, as a gift, sent a long glass frictional tube, which was then quite the rage in Europe. No sooner was the tube unpacked, than Franklin eagerly seized the opportunity to repeat the Boston experiments, as well as those described by Mr. Collinson, who had also sent an account of Muschenbroeck's bottle, as the Leyden jar was then generally known.

The subject greatly fascinated him and several of his friends and the power of points to draw off electricity from an excited body early engaged their attention. Electrical repulsion and attraction were carefully observed. He also proved that the electricity resided in the glass of the Leyden jar and that the electric spark was the sudden restoration of the equilibrium of the opposite electricities.

After proving the correctness of his plus and minus theory of electricity by numerous experiments, he began to investigate the part played in nature by electricity, and was led to the idea of the lightning rod by the tendency which lightning discharges have for taking place in line with the tops of the spires of churches and masts of ships—in fact, all projecting bodies pointing toward electrified clouds, commonly called thunder clouds.

After describing in a letter to Mr. Collinson, dated July 29, 1750, an experiment in which a pointed punch, (a miniature lightning rod) had harmlessly conducted electricity between two small metal scales, artificially charged, to represent the clouds and earth, he says:

"If these things be so (referring to the discharging power of points), may not the knowledge of this power of points be of use to mankind in preserving houses, churches, ships, etc., from the stroke of lightning, by directing us to fix on the highest points of these edifices upright rods of iron, made as sharp as a needle, and gilt to prevent rusting, and from the point of these rods a wire run down the outside of the building into the ground, or down round one of the shrouds of the ship, or down her side till it reaches the water? Would not these points probably draw the electrical fire silently out of the cloud before it came nigh enough to strike, and thereby secure us from that most sudden and terrific mischief?"

This was the first suggestion of the lightning rod, and it will be noticed that the function of silent restoration suggested therein was only a possibility and not a positive fact as is claimed by many electricians and scientists even at the present time.

When Franklin made his famous kite experiment at Philadelphia, June 15, 1752, the overhead dark and highly charged cloud drew up, by induction, the electricity from the earth; and this flowing to and over the Leyden jar and iron key attached to the kite twine caused electric sparks to be created at the air gap of the Leyden jar and key. These electric sparks were similar to those observed at the air gaps



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From *Frank Leslie's Popular Monthly*.

*Fig. 3. Multiple and Diffusive Discharge.*

of lightning arresters connected with telegraph lines and other electrical circuits. These sparks were therefore the effects of the electricity drawn up by induction from the earth and not drawn from the clouds as was originally supposed.

The first lightning rod erected was applied in September, 1752, by Franklin to his house in Philadelphia; and by means of two bells connected therewith he observed the inductive effects during thunder-

storms. After 1749 he discarded all artificial electrical experiments and carefully observed the phenomena of lightning discharges.

In no part of his writings upon such observations is his sagacity better illustrated than in the following extracts referring to the tendency of the electricity of the clouds to divide and flow by numerous branches to unite with the opposite electricity of the earth.

"As electrified clouds pass over a country, high hills and high trees, lofty towers, spires, masts of ships, chimneys, etc., as so many prominences and points draw the electrical fire and the whole cloud discharges there."

"The electric fluid moving to restore the equilibrium between the cloud and the earth, takes, in its way, all the conductors, it can find, as metals, damp walls, moist wood, etc., and will go considerably out of direct course for the sake of the assistance of a good conductor."

The great merit of Franklin in his electrical experiments and investigations of nature was the soundness of his method. Had he lived in the last century he would have, undoubtedly, determined all the electrical actions attending lightning discharges, and also the proper lightning protection requirements. It is only since the introduction of underground water and gas pipes, railway tracks, wire fences, overhead and underground electrical circuits and the art of photography, that it has been possible to fully determine the great area of electrified earth and the true character of lightning discharges, which vary according to different conditions of the earth's surface, height of clouds, etc.

### **Lightning Discharges Cannot Be Prevented.**

After an experience of about fifteen years with lightning rods it became apparent to Franklin that a pointed metal rod could not perform the function suggested by him in 1750, of silently tapping the electricity contained in a cloud and preventing lightning discharges in the vicinity of the building, and particularly one of ordinary height, to which it is applied.

A number of cases are cited by Franklin and others in which the rods were struck by lightning discharges; the only damage usually done was to tear up the earth around the base of the rod. In fact up to the introduction of water and gas pipes into buildings, the Franklin rod was a fair success. This is accounted for by the fact that in those days lightning discharges were principally of a diffusive nature, dividing into numerous branches, as shown in Figures 2 and 3, of which the rod received one branch and adjacent houses, trees or other objects received the other branches. This is quite evident from the diffusive



from Frank Leslie's Popular Monthly.

*Fig. 4. Lightning Discharge From High Cloud. Eiffel Tower, Paris.*

effects of lightning discharges as described by Arago and other early meteorologists of the last century.

The camera reveals the fact that when lightning discharges take place in line with forests and in rural sections, where there are no water, gas or other similar pipes, nor railway tracks, wire fences or other long metallic conductors, they are invariably of a diffusive nature as in Franklin's time; but where the long metallic conductors referred to exist, the discharges are, as a rule, of the concentrated form.

A lightning discharge has a hundred fold greater attraction for the interior gas, water and similar metal pipes of a building than for the original Franklin rod. Since the introduction of such pipes and other long metallic conductors, and of metal roofs connected with the earth by metal leaders, drain pipes, etc., the lightning discharges in cities, towns and other places are concentrated; and different requirements are now necessary for protecting buildings. The Franklin rod will prevent a telegraph pole from being shattered, and in the form of a vertical elevator is a success in connection with a high stone structure like the Washington monument. But it is invariably a failure when applied to a barn, an ice-house, a church, or any well-filled building of considerable area.

Not only the Franklin rod is obsolete, but also its ordinary ground connection at a single point, even for the arresters of electrical circuits as now employed.

There has been a reduction in the number of lightning discharges after the application of lightning rods to spires of some churches and other high structures, which, however, is only in connection with low clouds.

With low clouds the Eiffel Tower; 985 feet in height, prevents lightning discharges in its immediate vicinity, but it has been struck on a number of occasions by discharges from high clouds.

M. De Lisle, a member of the French Academy of Sciences, by trigonometrical observations measured the vertical height of clouds in a thunderstorm, over Paris, and found it to be about 25,000 feet.

The fact that lightning discharges also take place in line with the Washington monument, 555 feet in height, churches, skyscrapers and other high structures, fully prove that electrified clouds are generally high and that lightning discharges cannot be prevented.

The numerous telegraph, telephone, electric light and other electrical circuits do not relieve the electric tension during thunderstorms and prevent lightning discharges as is generally supposed. In fact many of them have no direct connection with the earth.

Nature has provided lightning discharges for our welfare, and they ought not to be prevented. They generate ozone, which neutralizes the miasma of the air and thereby prevent epidemics.

They also combine gases held in suspension and produce chemical agents which are essential for the growth of vegetation and plants.

### **Why Lightning Protection Requirements are Generally Unknown.**

There is no subject which is so imperfectly understood and upon which more nonsense has been written than that relating to the true

character of lightning discharges between the clouds and the earth. This is principally due to the fact that the great area and depth of earth or water intensely electrified and participating in such lightning discharges, have not been investigated by those who have been posing as authorities upon the subject of lightning protection.

Since the days of Franklin, almost every scientist has erroneously resorted to Leyden jar and other artificial electrical experiments as illustrative of a lightning discharge and have accepted them as such without any investigation of the real thing.

It seems as if they had taken it for granted that because Franklin

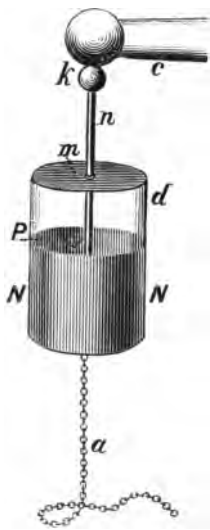


Fig. 5.

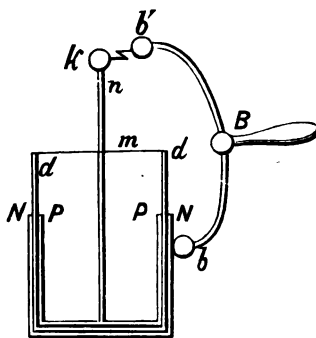


Fig. 6.

used the Leyden jar in his first electrical experiments, they should continue its use.

They have overlooked the fact that after his suggestion of the lightning rod in 1750, he discarded the Leyden jar, and carefully observed the actions and effects of lightning discharges which gradually revealed to him the fallacy of his deduction from the miniature lightning rod experiment.

In order that a proper comparison can be made between a Leyden jar and a lightning discharge, the former is illustrated in Figs. 5 and 6. It consists of a glass jar, *d*, coated inside and outside with tin-foil, *P* and *N*, for about four-fifths of its height. The mouth is closed by a piece of cork or wood, *m*, through which passes a metallic rod, *n*, terminating above in a knob, *k*, and connected below with the inner coating, *P*, either directly, as shown in Fig. 6, or by a chain hanging down

from it, or by pieces of tin-foil with which the jar may be filled. When electricity is accumulated from the prime conductor, c, Fig. 5, of an ordinary frictional electrical machine by means of the knob, k, and rod, n, to the inner coating, P, and the outer coating, N, is connected with the earth by a chain, a, the inside coating becomes positively electrified, and by the power of electric induction across the glass, d, or dielectric, as it is technically termed, the outside coating, N, becomes negatively electrified.

By placing one knob, b, of a discharger, B, in contact with the outside coating, N, and bringing the other knob, b', close to knob, k, as shown in Fig. 6, a small spark will pass between them. This is technically known as a disruptive discharge.

Attention is especially called to the small area of electrical accumulation of the tin-foil coatings of the Leyden jar and the fact that its puny discharge takes place between two knobs or points. But in the case of the electrified clouds and earth, the area of intense electrification is miles in extent, and frequently the equilibrium between the clouds and the earth can be restored only by a series of simultaneous discharges at different points, widely separated.

At the time of a discharge, the electrical actions in the clouds and earth and between them are on a gigantic scale, while in the Leyden jar or any other artificial electrical experiment, they are comparatively infinitesimal.

During 1892 a work on Lightning Conductors by O. J. Lodge, Professor of Physics in University College, Liverpool, was issued which is the outcome of a number of Leyden jar experiments made by him. The principal inference to be drawn therefrom is, that lightning discharges are of an oscillatory character, see-sawing through the air between the clouds and the earth, and thereby giving rise to the varied phenomena attending them. We are not dealing with the insignificant Leyden jar and its puny discharge, but with the great electrical generation of nature, miles in extent, and with discharges varying in length from 500 to 25,000 feet, according to the height of the clouds.

The camera clearly reveals the fact that the opposite electricities of the clouds and earth while quickly uniting, select a number of the shortest and most direct paths possible, wherever favorable conducting conditions exist.

When we consider its great length it is not at all likely that a lightning discharge has both a direct movement tendency and also an oscillating or indirect movement.

Attending lightning discharges, electric waves flow in all directions and by means of a coherer, similar to that used in wireless telegraphy,

notice of distant thunderstorms are given from one to three hours in advance. Prof. Joseph Henry observed many years ago, that the wave effects at a distance from lightning discharges were simply the effects of such discharges, but he did not assume that the discharges themselves were of an oscillatory nature.

Furthermore he made over two thousand experiments with the Leyden jar and maintained that, there was no analogy between it and the thunderstorm. He was a thorough, practical scientist and having carefully observed the effects of lightning discharges, for many years, his opinion is well worthy of consideration.

### Blunders of Scientists

That the lightning protection subject has been treated in a very careless and unscientific manner is quite evident from the many blunders that have been made in nearly every work on the subject.

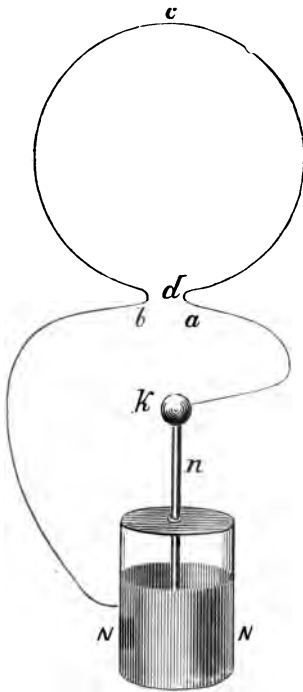


Fig. 7.

The old and familiar Leyden jar experiment shown in Fig. 7, is the only one that has any bearing upon the lightning protection subject. It consists of a long wire, so bent that the two parts, a and b, approach to within about a quarter of an inch of each other. If the extremities of the wire are brought in contact with the knob, k, and the outer coating, N, of the charged Leyden jar, the largest portion, if not the whole of the opposite electricities thereof, will pass as a spark across the air gap, d, separating the parts a and b, and not over the indirect portion, c, of the wire. But the entire current of a galvanic battery will flow over the entire wire, a, c, b.

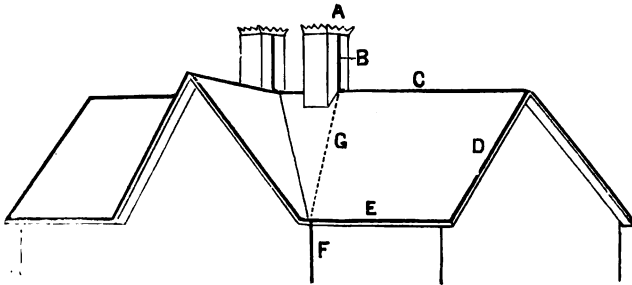
It shows the difference of electromotive force of electricities of high and low potential and demonstrates that in restoring the equilibrium between opposite electricities of high potential, the discharge will take place over the shortest path, even of high ohmic resistance in preference to an indirect or circuitous metallic path.

Several similar experiments were made by Prof. Lodge from which he suggested the impedance or choke coil for electrical circuits. From the following blunder, it is quite evident that he, as well as the others



named, have not investigated the actions of lightning discharges, which pursue even less indirect paths than artificial electricity.

The arrangement of conductors shown in Figure 8, by the heavy lines, B, C, D and E, between the metal cap, A, upon the chimney and the vertical conductor, F, extending from the eave of the roof to the earth, was shown in Prof. John Phin's work on Lightning Rods, issued in 1871 and was reproduced with an additional conductor, along the valley of the roof, in the original work of Richard Anderson issued in 1880 and also in that of 1885 which was revised by Dr. R. J. Mann.

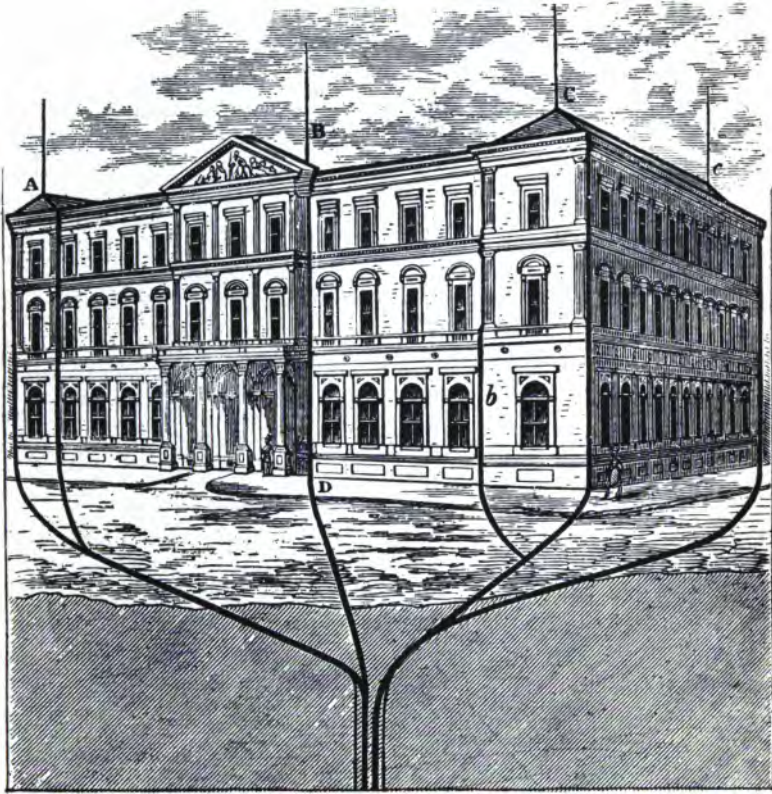


*Fig. 8.*

It is also shown in the work of Prof. Lodge as a protected building and is a violation of the simplest elementary principle of lightning protection. Hundreds of cases can be cited where lightning discharges have evaded such indirect metallic paths and passed in a direct path shown by the dotted line, G, over the wooden rafters, sheathing, and slate of roofs.

In Figure 9, is shown another system of lightning conductors, principally applied to buildings in Europe and is illustrated in both works of Richard Anderson and reproduced in Prof. Lodge's work as an elaborately protected building. This arrangement of conductors, concentrated at a central point in the earth, fully accords with the usual erroneous idea obtained from Leyden jar experiments, that the lightning discharge principally takes place between a cloud and a point upon the earth and that all attending phenomena are mere surgings or side flashes. The said arrangement is a violation of the fundamental principle of proper lightning protection, and was first suggested by Prof. M. Melsens, of Brussels, Belgium, who was in the habit of showing the harmless effect upon birds in a metal cage, when subjected to artificial electrical discharges and he therefore maintained that a similar arrangement of lightning conductors should be applied to buildings.

The Hotel de Ville, Brussels, was equipped by him and was regarded as the best protected building in the world.

*Fig. 9.*

From the top of its pinnaced spire, 297 feet high, eight main conductors extended to metal junction box just above the earth and located at a central point of the building, from which radiated three bundles of iron conductors, one leading to a vertical cast iron pipe, two feet in diameter and eight feet long, sunk in a well; the second attached to the service pipe of the city water system and the third to the gas main, at a moist point of street, thereby providing a very indirect path between the system of lightning conductors and the gas main.

There were also 426 air terminal points employed upon the top of the spire and also at different points of the ridges, parapets and turrets and these were connected by branch conductors with the main conductors so that the whole arrangement constituted a series of rather indirect metallic paths. During a thunderstorm in July, 1888, a gas pipe in the building was ignited and caused a fire, owing as above stated to one of the main paths being very indirect. In fact

the improper arrangement of lightning conductors about buildings, and also in connection with electrical circuits is quite common.

Prof. J. S. Trowbridge, of Harvard University recently advanced a theory that lightning discharges do not take place in line with water, basing it upon certain laboratory experiments made by him with a battery current of 20,000 cells. That they do not take place in line with water is a fact well known to sea-faring men and residents along the sea-coasts, bays, lakes and other inland waters.

A number of discharges in line with water have been photographed and comparatively direct paths are shown, indicating that the opposite electricities while thus uniting meet with little retardation, while on the other hand lightning discharges in line with earth of a rocky nature, chalk, or of great resistance, and especially when the water-bed is at a great depth, pursue irregular paths through the air owing to the retardation offered to the opposite electricities. It is a well established fact that lightning discharges are quite frequent along water courses, swamps, marshy sections and points where the water-bed is close to the earth's surface. Even while passing through the air their paths are determined by dense sheets of rain, and will greatly spread out during heavy rain-falls.

When there is a great accumulation of electricity above a river of ordinary width, the discharges frequently select telegraph wires, railway tracks, gas and water pipes, along or near the shore, for the reason that these wires, tracks and pipes enable the electricity of a great area of earth to more quickly unite with the electricity from the clouds than by way of the water of the river.

There are a number of Lightning Research Committees in Europe composed mostly of scientists and their object is to arouse interest in the work of contriving methods of absolute protection for buildings against damage or destruction by lightning discharges; the one in London having been founded about twenty-five years ago, under the auspices of the Royal Institution of British Architects.

They are apparently no nearer the solution of the subject, than when they started. This is not at all surprising, when we consider that no efforts are made to properly determine all the phenomena attending lightning discharges.

Lightning discharges clearly reveal their actions and indicate by the paths they select what they want, but the scientists have not yet been able to properly deduce therefrom their proper requirements.

### **Formation of Thunderstorms.**

In ordinary fine weather the upper regions of the atmosphere are at a different electrical potential from that of the earth, but the

difference in potential is not sufficient to cause a disruptive discharge to take place over the intervening space.

Certain conditions of temperature, atmospheric pressure and moisture favor the development of thunderstorms and under such conditions the potential difference between the clouds and the earth and objects thereon is suddenly increased, and more often locally than simultaneously, over a large extent of territory.

The causes of the electrical manifestations in a thunder-storm have not yet been clearly determined, but as certain conditions of heat, wind and moisture are present in the formation of thunderstorms, it is supposed that motion, whether of the wind, causing friction between the air particles; or when water-vapor is rapidly condensed into a liquid, is in some way the cause of the increased electrification of the air, or the disturbed condition of the normal electric field.

A thunderstorm generally takes place between those portions of the atmosphere in strong thermal contrast, by the descending cold air flowing in irregular currents in advance over the surface of the earth and lifting the warm air in an irregular manner producing irregular masses of clouds. As the flow of the descending cold air increases, the condensation of aqueous vapor also increases and begins to be precipitated.

The great violence with which the warm air rushes over the cold air, so different in temperature and density, produces a great condensation of vapor and generation of electricity, so characteristic of these storms. A striking illustration of the thermal conditions under which a thunderstorm is produced, is afforded by the balloon ascent from Chambersburg, Penna., made on July 29, 1871, by Prof. John Wise, the veteran American aeronaut and meteorologist. When less than eight thousand feet above the earth's surface he entered a well marked snow storm and on the same occasion while nearer the earth he observed a thunderstorm.

The distance between the lower part of the thunder-clouds and the earth has been found to vary from 500 to 25,000 feet, according to the topography of the country and other circumstances. In this country, the average height of these clouds above the earth is estimated at 2,500 feet. It is only in the so-called cloud-burst, a tornado or a rotary storm, that the cloud reaches the earth, and then produces pitchy darkness.

The area of thunder-storms depend upon the configuration of the earth's surface, and also varies with the latitude and longitude and general climatic conditions.

Thunderstorms occur with considerable frequency over all the territory east of the 100th meridian, excepting a narrow strip along the

northern border. West of that meridian, except in the Rocky Mountains, the frequency steadily diminishes until it is practically zero at the Pacific Coast.

The general direction of approach in the United States is from the West. At Key West, Fla., however, the approach is from the East, and at Galveston, Texas, from the Northeast, North, or Southwest.

A snow storm, accompanied with a high wind, is also attended with great generation of electricity and lightning discharges.

Lightning discharges also attend volcanic eruptions, due to the vapor of water, heated air, etc., quickly ascending to a great height and over a great area and a consequent great generation of electricity.

### **The Great Electrification of the Earth.**

Electric induction takes a prominent part during a thunderstorm, and through its influence the path or paths are determined over which a disruptive discharge takes place between two clouds, or layers of a cloud, or between the clouds and the earth.

A highly positively electrified storm-cloud or clouds cause by induction acting through the vapor particles of the intervening air, the earth beneath and everything thereon to become intensely electrified; the air nearest the earth, being also more or less negatively electrified.

Attention is especially called to the fact that the area and depth of earth highly electrified by induction is about equal to the area and depth of the great electrical generation and accumulation in the overhead clouds, and it is principally to a want of knowledge of this important fact, that investigators have failed to determine the true actions in and upon the earth attending lightning discharges.

The area of earth thus intensely electrified in many cases extends over a circle from one to three miles in diameter; and judging from the destructive effects in deep underground mines, the explosion of submarine torpedoes and killing of fish, during thunderstorms, such electrification extends deep into the subterranean water-bed and bodies of water and not merely upon the surface of the earth and water as is generally supposed. The underground water, gas, and other similar metal pipes, the rails of steam and electric railways, wire fences, overhead and underground electrical wires within the area above referred to, also become highly electrified. Even the stone, brick, slate and other non-metallic material of buildings become electrified by induction, but not as intensely as the water, gas, heating, ventilating and other metal pipes, metal lathes and wire netting of plastering, metal roofs, ridgings, crestings, gutters, leaders, smokestacks, fire

escapes, interior electric light and other wires, steel frame-work of skyscrapers and their deep iron caissons and other metal work about buildings or other structures.

The clouds during a thunderstorm are sometimes so dense and highly charged with electricity, that they cause, in the midst of the obscurity, a vivid light to rest on bodies upon the surface of the earth. Mention is made of luminous rains, during which the ground seemed to be on fire. Travellers have on a number of occasions been seized with alarm on seeing their wet clothes all aglow on stormy nights.

These luminous effects are caused by the inductive influence of the electricity of such clouds, which causes the electricity of the earth to manifest itself. While in the act of discharging into the air, the electricity of the earth has often been seen tipping with light, in the form of a star or brush, the masts and spars of ships, known to sea-faring men as St. Elmo's fire, also edging with light the manes of horses, the metal trimmings of their harness, the lashes of whips, the brims of hats, the tops and edges of umbrellas, the sharp points of swords and lances, the extremities of hair and whiskers, the corners of chapeaux, the buttons upon the coat, filaments of straw, the beaks of birds, and the myriad needle-like terminations of vegetable growth, with that incomparable point and finish which they took from Nature's own hands.

During the past ten years numerous experiments have been made with flying kites from lowlands and also from elevated points, about 2,000 feet above the sea level, which have revealed the electrical potential of the lower air region during clear weather, high winds, snow storms, before and during thunderstorms. It is claimed that during thunderstorms a potential of about 3,000 volts has been measured at the top of Washington Monument and a potential of about 10,000 volts at the top of the Eiffel Tower.

They simply indicate the intensity of the induced electricity then flowing into the air from the earth, and not the enormous voltage of lightning discharges.

### **Lightning Discharges**

When the attraction between the positive electricity of a cloud or clouds and the negative electricity of the earth, is able to overcome the resistance offered by the intervening air, simultaneous electrical movements take place within a great area of the clouds and also within a similar area of earth and water and a rushing together and neutralization of such opposite electricities are effected by a series of successive discharges, producing the vivid, quivering flashes, known

as lightning discharges, which are sometimes of quite perceptible duration.

A lightning discharge is therefore the joint effect of such opposite electricities and they usually unite just above the earth's surface or objects thereon, and especially where there is a large body of water, swamps, surface earth of good conductivity and where the subterranean water-bed is not at a great depth.

Where the surface earth is of a rocky or other poor conducting nature or the water-bed is at a great depth then they unite within the earth's surface, shattering solid rock for quite a depth, and in deep sandy districts the electricity from the clouds marks its path through the surface earth by making hollow vitreous tubes therein, known as fulgurites, which vary from 5 to 75 feet in depth and from one half to four inches in diameter. They are generally of a spiral form, with lateral branches contracted in form toward the lower extremity.



From Frank Leslie's Popular Monthly.

Fig. 10. Electricity Flowing Within Great Area Toward Line of Discharge.

Opposite inductive electrical effects and discharges also take place between layers of a cloud or between adjacent clouds and under certain conditions, between an apparently clear sky and the earth.

The light produced and known as *lightning*, is due to the resistance offered by the air to the passage of the opposite electricities., while the sudden separation and reunion of air produces the violent report and rumbling noise known as *thunder*. While the passage of light is almost instantaneous, sound only travels at the rate of about 1,100 feet per second, which accounts for the interval of several seconds between the lightning and thunder, although both are almost simultaneous. When the thunder is heard, all danger from that discharge is past.

It is claimed that a lightning discharge is visible for about 150 miles, while, as a rule, thunder cannot be heard more than ten miles.

The flashes of light sometimes observed during a summer evening, without thunder, and erroneously termed *heat lightning* are merely the light from discharges in a thunderstorm at a distance between the horizon of the observer and the horizon seen from the place where the flash occurs, reflected from the upper clouds thereof, or from the air itself as in twilight. Such flashes were observed in the distant horizon from a telegraph office in Pittsburg, Penna., while a thunderstorm was raging at Carlisle, Penna., about 250 miles distant.

Lightning discharges vary in form according to the height of clouds, the conductivity of the earth's surface and objects thereon and within, and the downfall of rain and speed of the wind.

When a cloud is high and there is a great body of water, a swamp or earth of good conductivity beneath and especially long metallic conductors within or thereon, the discharges are generally concentrated in form and flow in from one to three paths, comparatively direct in their course. While in line with rock formation or other unfavorable conditions, the path



Fig. 11. Low Cloud, Heavy Rainfall.

or paths are irregular or circuitous, and during a heavy rainfall there is usually one or more main paths and a number of weaker lateral branches, which appear to die away before reaching the earth, while in reality they are greatly diffused by the dense rainfall.

When a cloud is low, discharges usually spread out into a number of adjacent branches, and when attended with a heavy rainfall, the diffusion is so great as to give rise to the *sheet lightning* effect as shown in Fig. 11, and owing to the comparatively small damage done are sometimes erroneously called cold strokes.

### Lightning Photography.

Prof. John Wise who has been in and above thunderstorms reported that at the time of a lightning discharge numerous streams of electricity were noticed flowing within a great area toward a central low point of cloud formation and the flow of electricity from the cloud to the earth usually appeared from above like a long drawn-out spiral, while to a person upon the earth it appears to pursue a zig-zag or irregular path.





Wm. Archibald.

*Fig. 12. Electricity Flowing Within Great Area Toward Line of Discharge. Newark, N. J.*

His observations have since been fully confirmed by the stereoscopic camera which clearly reveals the spiral path of lightning discharges, the flow of electricity within a great area of cloud formation toward a central point or points thereof and also all other actions under different conditions.

The work of W. N. Jennings, of Philadelphia, the pioneer of lightning photography and also of Wm. Archibald, of Newark, N. J., deserve special mention.

When the thunder clouds form they are in their element and for many years past they have photographed lightning discharges under different conditions. Their work has attracted the attention of scientists and meteorologists throughout the world. The pictures secured

by them are extremely interesting and have greatly aided in determining the different electrical actions under varying conditions.

In fact they have completely demolished the ridiculous theories advanced by laboratory experimenters in reference to lightning discharges. By mounting a camera on a vertical axis rotated at a uniform speed of clock-work, Dr. Wallter, of Hamburg, Germany, has secured a number of very fine photographs over the same path. The time intervals calculated from the movement of the apparatus, were found contrary to general anticipation to be irregular, which does



G. B. Davis.

*Fig. 13. Discharge With Good Earth Path. Heavy Rainfall.*

not accord with the oscillatory character of the lightning discharge as theorized by Prof. Lodge.

In addition to this irregularity of the succession of the flashes, it was found that the first and last flashes over the same course were generally the brightest, whereas if the flashes were of an oscillatory character, there would be a regular reduction of energy in all the succeeding flashes after the first one. In some cases as many as six separate flashes in one discharge were exhibited and the time intervals obtained in one case were 0.131, 0.068, 0.075, 0.119 and 0.013 seconds respectively.

The discharges shown in Figure 13 and 14, were photographed at Dubuque, Iowa, during the same storm and clearly reveal their actions under different earth conditions. The one in Figure 13, took

place in line with a point in the city about three quarters of a mile distant from the observer, while for the one in Figure 14, the camera was pointed directly east across the Mississippi River toward the Wisconsin bluff, the discharge taking place in line with a point upon the bluff about one and a half miles distant from the camera and where the conducting conditions of the surface earth were not as good as in the city. Mr. Davis also reports that



G. B. Davis.

*Fig. 14. Discharge Retarded by Poor Earth Path.*

discharges as revealed by the stereoscopic camera are spiral in form and that the latter named discharge is of a long irregular spiral form.

In this connection it may be stated that the path of a skyrocket through the air as revealed by such a camera is also of a spiral nature.

### **Electrical Actions of Lightning Discharges.**

There is undoubtedly a powerful flow of electricity within a great area of clouds toward a central point thereof, and also a simultaneous flow within a great area of water or earth, toward a ship, tree, barn or other isolated object or point, in line with which a lightning discharge takes place.

In such cases, especially in the rural districts, the quantity and intensity of the opposite electrical charges are so great as not to be able to unite at a single point.

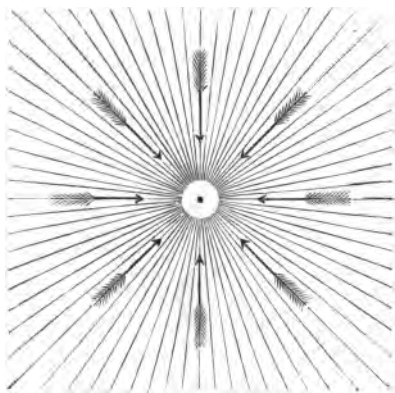
This accounts for the failure of the ordinary lightning rod and for all the phenomena attending such discharges.

It was customary at one time to apply a single wire rope or linked chain or rod from the top of the mainmast of a ship and over its side into the sea, as a lightning protector, but it was not a success. By employing metal strips with each mast and connecting them with the metal sheathing of a vessel, the electricity from the clouds usually divides into as many branches and readily unites with the electricity of the water flowing within a great area toward the metal sheathing and thereby proper protection has been secured for wooden ships. The steel masts and metal work of the modern ships afford proper protec-

tion. The great area and depth of intensely electrified water is revealed by the great number of dead and stunned fish taken out of inland waters after lightning discharges, in line therewith. All the fish in a certain pond were killed by a lightning discharge in line therewith and twenty-eight carts of dead fish were taken from Lake Kirknitz after a thunderstorm.

A recent case occurred on July 23d, 1902, when thousands of fish were killed during a thunderstorm in the River Havel, near Potsdam, Germany.

The opposite electricities have quite an attraction for all kinds of trees, but far greater for the oak, elm and other trees with great



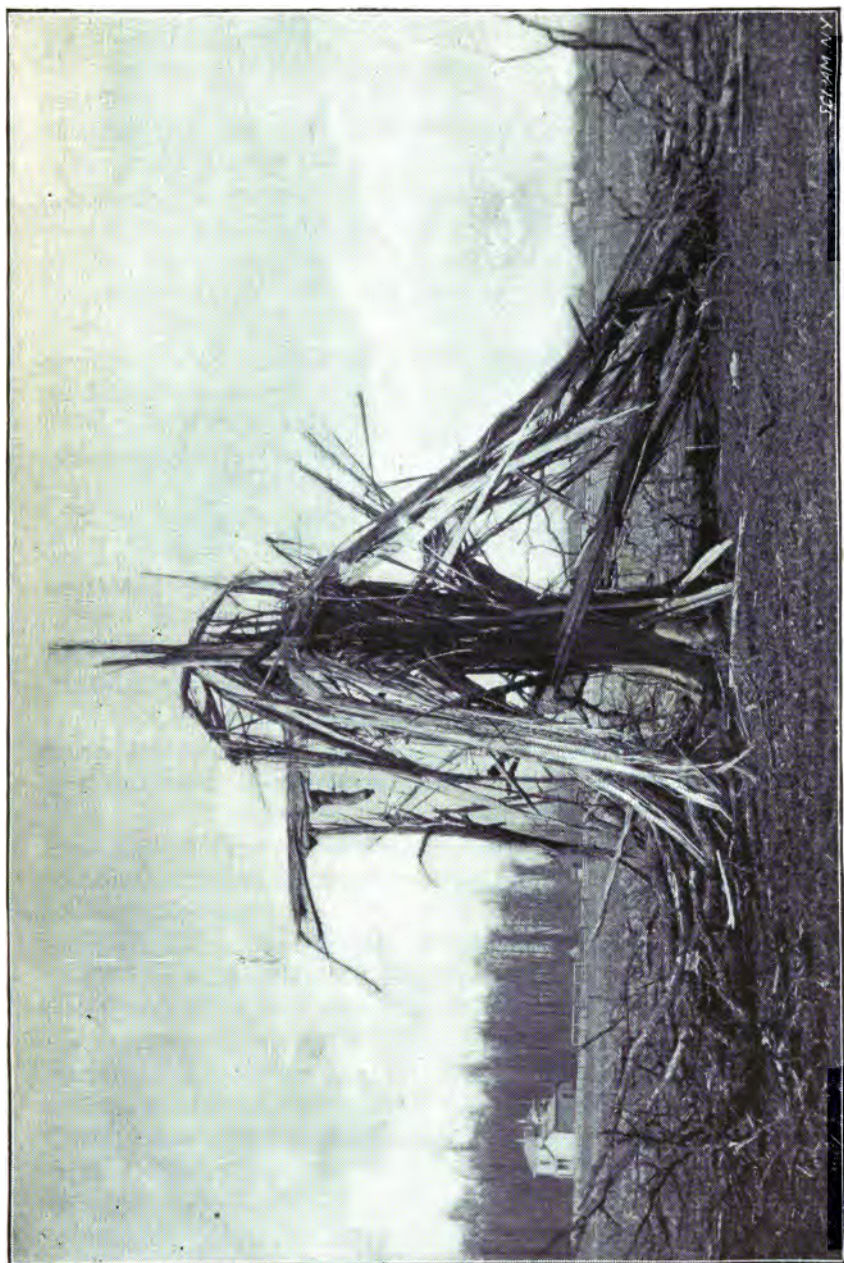
*Fig. 15.*

out-spreading branches and dense foliage than for poplar, pine, beech and similar trees with short branches and sparse foliage; for the reason that the former offer a wide scope of comparatively good conductivity for the electricity from the clouds to spread out in all directions over the long branches and dense foliage and unite by numerous paths with the electricity of the earth, which always flows intensely within a circle of from 3,000 to 5,000 feet diameter toward the tree as shown in Figure 15.

The central point indicates the trunk of the tree, while the union of the opposite electricities is principally effected in line with the outer branches and away from the trunk, and especially when there is a heavy rainfall, or persons or live stock are beneath the branches and thereby increase the conductivity of such paths about the tree. Of nearly 200 sheep huddled under a tall pine tree near Butte Creek, California, 52 were killed outright and the others stunned. This is but one of the many similar cases showing the great diffusive action of the electricity from the clouds while uniting with that of the earth.

In cases of enormous intensity and especially at the beginning of a storm, when there is little rainfall an isolated tree is practically annihilated as shown in Figure 16. The trunk is split and thrown outward and in some cases, slivers and branches are hurled hundreds of feet away; due to the action of the opposite electricities, while mainly uniting beyond the trunk.

Hay stacks, well filled barns, granaries, ice-houses, storage warehouses and lumber yards are more frequently struck and destroyed



Frank Woodmancy.

Fig. 16. Tall Burr Oak Near Sidney, Ohio, Shattered by Lightning Discharge.

From Scientific American.

SEP 24 1894

than any other objects or properties, for the reason that hay, grain, tobacco, ice, cotton, lumber and other compactly stored material, offer a wide scope of comparatively good conductivity for the opposite electricities to unite within a suitable area.

In Figure 17, is shown a lightning discharge in line with a barn which was ignited and destroyed. The tendency of the electricity from the clouds to spread out as it approaches the hay in the loft is clearly indicated. The theory usually advanced that such attraction is due to vapor arising from hay, grain and ice is erroneous.

During the eleven years, 1890-1900, 10,742 barns in this country were destroyed by lightning discharges. Of these cases 2,067 occurred in 1900. The tendency of the opposite electricities to unite by numerous branches or ramifications within an area, instead of a single point, is also revealed by their destructive effects in connection with a herd of cattle, a flock of sheep or a great assemblage of persons.

At Riverfalls, Wis., a discharge took place in line with the centre pole of a circus, killing eight and injuring twenty-five of the audience at different points, but none of the circus employees within the ring.

Horses at the opposite ends of a series of stalls in stables and persons in churches and buildings near the walls have been killed and injured while those in the central portions were not affected.

The wide scope and easy paths offered by metal roofs and their connecting metal leaders, drain and other pipes connecting with the earth, principally account for the immunity of buildings in cities from damage by lightning, while buildings in the suburban districts having metal roofs not metallically connected with the earth have been damaged or destroyed by terrific discharges.

Many cases can be cited which clearly indicate that the electricity of the clouds and that of the earth unite within a certain area or areas especially in the rural districts. This is to be accounted for by the fact that in doing so, they select the shortest paths for readily uniting and quickly restoring the disturbed equilibrium.

When a discharge takes place in line with an underground metal pipe or a railway track, the electricity flows from all directions of the earth toward such pipe or track, and two series of currents flow along such conductor toward each other, increasing in intensity as they approach the descending electricity from the clouds. When in line with a telegraph wire or wire fence, the electricity of the earth strongly flows within a series of circles, each about 500 feet in diameter with a pole or several fence posts as the center thereof, and thereby enable the opposite electricities of the clouds and earth to unite at a series of poles or posts within quite a distance; and if unprotected such poles or posts are invariably shattered. The earth currents flowing within



W. N. Jennings.

*Fig. 17. Discharge in Line With a Barn.*

each of such circles or area are not as powerful as those flowing toward an isolated tree or barn, although in the aggregate they are quite as powerful; for the reason that a greater area of intensely electrified earth participates in such discharges, and also in those in line with railway tracks and underground pipes. The different effects produced by lightning discharges upon objects upon the earth have given rise to the supposition that they are erratic, but the more thoroughly their actions are investigated, the more apparent is the fact that there are no freaks attending them.

It must not be supposed that the opposite electricities of the clouds and earth, pursue an experimental path or paths through the intervening air, objects and surface earth to unite with each other; on the contrary, before the slightest movement has taken place; every line or path which they will take, have, by induction, been selected and are clearly defined, and every effect produced, can upon a careful investigation, be properly explained.

A number of cases can be cited where lightning discharges have taken the same path at different times about churches and buildings.

There is a house at Dartmoor, England, that has been struck over 200 times in forty years. The partiality of the lightning for this house was noted soon after it was built; inside of a year the owner had to abandon the structure, it was struck so often.

During a very heavy rainfall lightning discharges are disposed to greatly spread out or divide into many branches, especially from low clouds. These branches vary in intensity according to the den-

sity of sheets of rain and surface earth conditions, and give rise to slight damage to buildings and the mere stunning of persons.



Wm. Archibald.

Fig. 18. *Diffusive Discharge, Newark, N. J.*

Many of the so-called freaks are caused by such discharges and are usually due to proximity of persons or objects to flowing water, metallic conductors in or upon the earth or about a building and the different lines of resistance caused by the presence of metals of varied sizes, lengths and positions about persons and objects.

The character of lightning discharges is principally governed by the conducting conditions upon or within the earth.

As previously explained a lightning discharge will greatly spread out over the branches of an oak or other similar tree, but if a telegraph or telephone wire is attached to the trunk or a wire fence is adjacent thereto, a lightning discharge will take place in line with the trunk and such wires and ignore the branches.

### **Attraction for Underground Pipes and Railway Tracks.**

Not only are the water, gas and other metal pipes in buildings electrified by induction, but also the street mains with which they are connected. The plexus of such underground pipes, in many cases of miles in length also provide an easy path or paths for the opposite electricity of the great area of water-bed to readily unite with that from the clouds.

It is principally by the destructive effects produced upon such



underground pipes, and especially upon the cement lined water-pipes and ordinary gas mains, that the great intensity of the electrical currents flowing within a great area of earth at the time of a lightning discharge have been determined.

The cement lined water pipes are usually made of sheet iron shells, 8 feet long and No. 18 gauge in thickness and are lined inside and outside with cement mortar, one half to one inch thick. Their ends are butted together and over butted ends is placed a sleeve about six inches long, fitted with cement to make a water tight joint. The iron of one length does not usually come in contact with the iron of the adjacent length, being separated by 1-8 to 1-4 inch of cement. In Fitchburg, Mass., the joints of about 2,000 feet of such pipe were destroyed on each occasion during five different thunderstorms and such destruction was the principal cause of the failure and abandonment of that class of water pipe, at Fitchburg, Lynn, Woburn, Arlington, Mass., and other places.

In each case of such pipe destruction the discharge took place in line with the interior water pipes of a building located about the centre of the line of damaged pipes.

The energy of lightning currents in the earth is sometimes powerful enough to melt the lead joints of cast iron water pipes, while the destruction of the lead and oakum joints of iron gas mains is a common occurrence during severe thunderstorms especially in towns and medium sized cities where the earth beneath them is of a rocky nature or poor conductivity, or the water-bed is at considerable depth.

In a report issued in 1900 by Carroll D. Wright, United States Commissioner of Labor, the average gas leakage loss of 355 gas companies in this country is stated to be about 14 per cent, of the total output.

This escaping gas accumulates in sewers, subways, vaults and cellars, beneath asphalt pavements, causing them to rot and is a constant menace to life and property.

A percentage of this leakage is, undoubtedly, due to the destructive effects of powerful underground lightning currents, which have in the aggregate an energy nearly equal to that descending from the clouds. Many cases can be cited in which the electricity from the clouds flowing in line with the ordinary insulated lightning rods upon churches and other buildings which terminated in the earth adjacent to the foundation walls thereof for a depth of from six to ten feet, and the electricity from the earth flowing along the underground gas and water mains and into the buildings via the service pipes, united during lightning discharges by breaking through the brick and stone walls separating the outside lightning rods from the

inside pipes, hurling out bricks and stone and in many cases melting the lead joints of gas meters and igniting the escaping gas. A number of such cases are also mentioned in the work of the Lightning Rod Conference held in England, about twenty years ago, in one of which, the opposite electricities while uniting broke through four and a half feet of solid masonry. Prof. Lodge referred to them in his work as surgings or side flashes; but they are, undoubtedly, the main paths of lightning discharges.

A number of cases can also be cited where the earth for a distance of from six to eighteen feet between the lower part of ordinary lightning rods and the underground water and gas pipes was torn up and the pipes were damaged by the powerful lightning discharges.

Underground terra-cotta drainage pipes, especially when connected with the metal rain leaders of buildings are also frequently shattered by lightning discharges and especially during a heavy rainfall. Owing to the destructive effects of underground lightning currents; glass, paper, wood and other non-metallic pipes cannot be successfully used on a large scale as underground water mains without the employment of a proper system of lightning protection; for the reason that the underground lightning currents and the electricity from the clouds have a great attraction for a long body of water in such underground non-metallic pipes: especially when connected with metal service pipes of buildings.

For the same reason the following methods suggested for preventing the destruction of the underground water, gas and other metal pipes by the trolley railway currents are also impracticable. The complete insulation of the outside portion of such metal pipes by insulating or poor conducting material; the insulation of the iron service pipes from the iron street mains by wood or other non-metallic material; also the employment at intervals with the iron street mains of non-metallic sections, as the underground lightning currents in their union with those from the clouds will undoubtedly shatter such insulating material or non-metallic sections especially where there is rock or earth of poor conductivity beneath the pipes. The destruction of the joints of underground metal pipes is also facilitated by such pipes being utilized as the earth terminals for lightning conductors and lightning arresters connected with electrical circuits.

Such pipes must, however, be used for such purpose. wherever present, but proper provision should be made to reduce the strain upon their joints by lightning discharges.

Persons who object to the application of lightning conductors to buildings upon the ground that they attract lightning discharges should bear in mind that the attraction of a lightning discharge is a

hundred fold greater for the interior, water and gas pipes of a building than for an ordinary lightning rod.

The opposite electricities of the clouds and earth during a lightning discharge have also a great attraction for the supply, distributing and any other metal pipes connected with an oil tank, or a series of such tanks, and being the highest object or objects connected with such pipes, the tanks are frequently selected as the points in line with which the opposite electricities unite. As the tanks and their connecting pipes usually rest upon the earth's surface a great resistance and retardation is thereby offered to the electricities while uniting causing a great heat to be generated at a point in the iron top of a tank, and also at all pipe joints of poor electrical conductivity.

The volatile gas generated in the tops of the tanks by the excessive heat during the summer season has also been a principal medium of such ignition.

Lightning discharges have also a great attraction for railway tracks, which also offer a wide scope within which the opposite electricities can unite.

A number of cases can be cited of discharges in line with locomotives and moving trains and especially with iron cars, like those used in the transportation of oil.

The attraction for railway tracks is further increased by the proximity of overhead wires, which aid in reducing the lines of resistance for the opposite electricities.

### **Attraction for Wire Fences, etc.**

Since the introduction of wire fences, lightning discharges have frequently taken place in line therewith, shattering the wooden posts at intervals for quite a distance and killing live stock in their immediate vicinity.

The several wires and also their many short wooden posts, in close proximity to each other, offer comparatively good paths for enabling the opposite electricities to readily unite within a great distance.

Between an ordinary lightning rod terminating for about ten feet in moist earth and an ordinary wire fence about 400 feet long, a lightning discharge has a greater attraction for the latter.

The former will serve as an earth terminal for a galvanic current, but is worthless for enabling the opposite electricities of the clouds and earth to readily unite. These facts are mentioned to show the difference between artificial electricity and the lightning discharge. Wire fences when properly grounded at suitable intervals can be safely employed as part of a proper lightning protection system, especially for buildings in the rural districts.

The following are a few of the many cases of live stock, etc., killed in connection with wire fences.

Out of 266 head of live stock killed by lightning discharges in Iowa during 1897, 118 were found in close proximity to wire fences and in some cases the fences were struck at considerable distances from the points where the stock was killed.

While a herd of 800 cattle were being moved from one pasture to another in Finnis County, Kansas, through a narrow lane hedged by a wire fence, a lightning discharge took place in line with the wires thereof, instantly killing twenty-five that were crowded against them.

Sixteen fine dogs were killed on the grounds of the Brooklyn Gun Club, Smithtown, L. I. These grounds are 200 by 150 feet in dimensions, and are enclosed by a wire fence and other wires extending into the enclosure, and to these wires the dogs were fastened by chains. Of forty persons leaning against a wire railing at the Charlottenburg cycle track, Germany, three were killed, twenty severely, and the rest slightly injured. About a dozen persons, mostly women, were killed in this country in one year, while in the act of stripping clothes from wire clothes-line or coming in close proximity thereto during a thunderstorm.

During a running race at an Illinois county fair, the winning horse was struck dead as it won the race by a head under the wire, while none of the other ten horses was hurt, although most of them were close up at the finish.

A great many similar cases can be cited, all showing the great attraction of lightning discharges for horizontal metallic conductors, especially those of considerable length.

### **Attraction for Overhead Electrical Circuits.**

During a thunderstorm, all overhead and even underground electrical circuits, became highly electrified by induction. They are frequently selected by lightning discharges, for the reason that they also offer wide scopes within which the opposite electricities of the clouds and earth can unite.

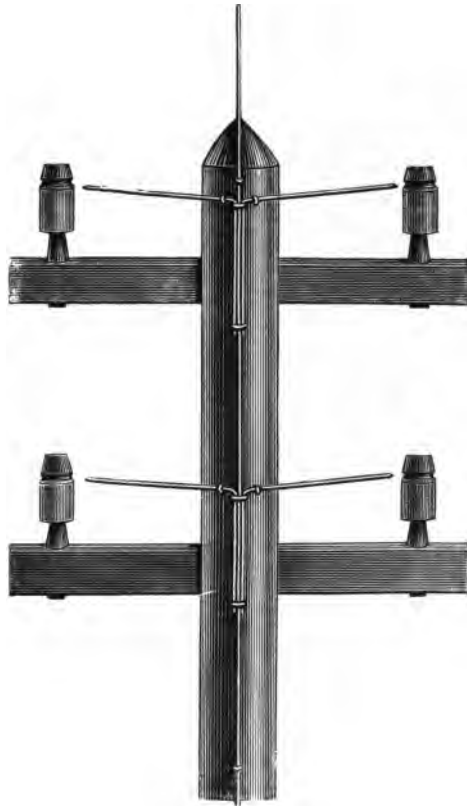
The first telegraph line between Philadelphia and New York had been in use but a short time when it experienced the destructive effects of lightning discharges. On May 20, 1846, a discharge in line with the wire upon a high pole at the Hackensack River, shattered the poles at intervals within a mile upon each side of that point. During another storm shortly afterward over twenty poles were shattered.

The author was employed by the Philadelphia & Reading Railroad Company at Reading, Pa., for over twenty years, in the capacity of telegraph operator and superintendent of telegraph, and from his

first connection therewith in 1859, observed the great attraction of lightning discharges for the overhead telegraph wires. The shattering of many poles at intervals by single discharges was the first revelation to him that the earth was intensely electrified within a great area, and that the tendency of the opposite electricities was to unite at numerous points within a great distance or area. Since then, the correctness of this deduction has been fully confirmed by many investigations of the effects of lightning discharges.

The distance within which such poles are shattered and the intervals of poles selected, vary according to the area of earth intensely electrified and the conductivity thereof. Discharges in line with a telegraph wire along the Schuylkill Canal in Pennsylvania have on several occasions shattered poles adjacent to each other, while along the railway they were usually selected at intervals.

The arrangement of the lightning conductor shown in Fig. 19 was first employed about forty years ago, not only to prevent the poles being shattered, but also the cross arms and insulators; every third pole thus equipped and grounded



*Fig. 19.*

effectually prevented the destruction of the poles and cross arms.

About thirty years ago the paraffine insulator was introduced and used by a number of railroad companies in this country. It consisted of a glass bottle which separated an iron wire support from an iron shield, which was supported in a cross-arm by a lug or was screwed fast to a pole.

Its insulating properties were good at the start, but during every summer season the bottles were cracked by lightning discharges where the defect could not be seen. Upon investigation it was found that

from twelve to thirty-five such insulators were thus impaired by single lightning discharges, thereby also indicating the wide scope and numerous points at which the opposite electricities united.

A terrific discharge from a high cloud in line with an unprotected telegraph wire is attended with destructive effects in the nearest telegraph offices, even if they be several miles distant.

During last July when the construction force of the Southern Bell Telephone & Telegraph Company were stretching wire and working in two sections, about five miles apart, near Offerman, Ga., three men were killed and one injured in one section, and two killed and one



R. W. Rea.

*Fig. 20. A Retarded Lightning Discharge. Menominee, Mich.*

injured in the other section, by a single discharge in line with the wires; thereby indicating the great area of earth intensely electrified in connection with high clouds.

A number of discharges in line with overhead electrical circuits have been photographed, one of which is illustrated in Figure 20, showing two paths from the clouds in line with a three wire incandescent electric light circuit. The neutral wire was not grounded and the safety fuses of a number of buildings within quite an area were blown out. The main charge pursued a very irregular course indicating considerable retardation offered to the opposite electricities while

uniting, which was partly due to the lack of proper lightning paths between the wires and the earth.

That discharges in line with overhead electrical circuits have increased during the past twelve years is quite evident from the statistics of such fires in connection with telegraph offices, telephone exchanges, electric power stations, and especially railroad depots and buildings in the rural districts.

The fact that lightning rods are still being applied to the wooden poles supporting telegraph and other overhead electrical circuits, not only in this country, but also in Europe, in order to prevent them being shattered, is conclusive inference that lightning discharges do take place in line with overhead wires.

An assertion has been made and published that lightning discharges seldom take place in line with overhead electrical circuits. This is not in accordance with the facts, especially in the suburban districts.

### **Electrical Actions Between Metallic Conductors.**

The great attraction of the opposite electricities of the clouds and the earth for underground pipes, and for railway tracks, overhead and underground electrical circuits, etc., is also attended with electrical actions between them during lightning discharges wherever they are in proximity to each other, giving rise to what are erroneously known as static discharges, surgings or side-flashes.

The fact is that during a discharge there is a general electrical movement in all long metallic conductors as well as in the earth, within the area of intense electrification, toward the line of the main discharge or discharges; the induced electricity in one conductor flowing into another conductor offering the shortest path toward the line of such discharge.

The small flashes noticed on electrical circuits, simultaneous with lightning discharges, are therefore not surgings or side flashes, as generally supposed, but part of the great electrical movement of the earth participating in its union with the electricity from the clouds.

Such action is clearly revealed on an extensive scale in connection with the circuits radiating in all directions from telephone exchanges, where the induced electricity of a number of circuits flow toward the exchange and thence via those circuits or ground conductors which offer the shortest paths toward the main electric discharge or discharges from the clouds.

It is also frequently manifested in the passage of such induced electricity from insulated electric light wires in buildings to a conductor connecting with a gas, water or other extended grounded con-

ductor, whereby a hole is made in the insulation of such wires, which is invariably enlarged by the dynamo current.

During the past three years the paths selected and effects produced by the induced electricity of electric light wires in a building connected with an underground circuit about 2,000 feet long, located in a suburban section, have been noted and the insulation of such wires have been thus impaired during every terrific thunderstorm, even with discharges a mile or more distant.

There is, undoubtedly, considerable impairment of the insulation of electric light wires from this action, and this is aggravated by the circuitous paths of such wiring in many buildings.



Walter Sprange.

*Fig. 21.*

*Fig. 22.*

*Fig. 23.*

*Branch Lightning Discharges Between Overhead Wires and Rails About 1 a. m., August 6, 1896. Beach Bluff, Mass.*

This action is not confined to conductors in close proximity to each other, but is observable even where there is quite a separation, as shown in Figures 21, 22 and 23, between overhead wires and the rails of a railway track.

The three photographs were taken within five minutes. The camera was stationed on the awning over the platform of the railroad depot, which is located about 130 feet this side of the country road crossing shown in Fig. 24. Along the country road which crosses the railroad two electric light wires from Lynn, four miles distant, and a fire alarm wire from Swampscott, two miles distant, are supported upon poles; two wires being above the third. There is also a warning sign, about fifteen feet high, at the crossing, and its top is about ten feet from the lower overhead wire.





Walter Sprange.

*Fig. 24. Road Crossing Near Railroad Depot, Beach Bluff, Mass.*

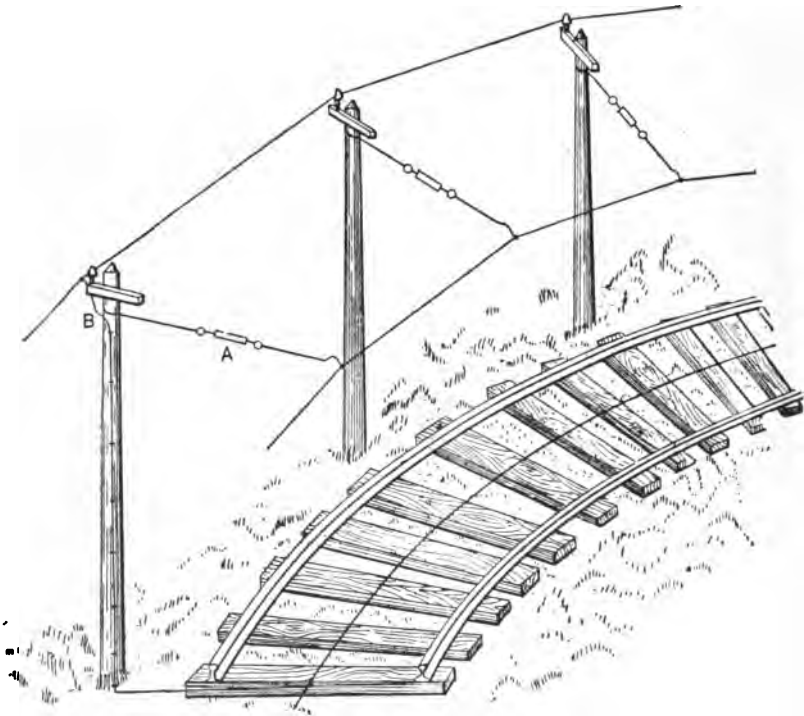
The flow of electricity from the clouds to the wires or wire took place at a point or points along the country road distant from the railroad.

It is possible that all the discharges took place between an upper wire or wires and the rails with the lower wire as part of the paths; that portion between the upper and lower wires being only partially shown in the second discharge (Fig. 22). The first discharge (Fig. 21) was apparently in line with one line of rails and the flowing water of an adjacent gutter, while the other two were in line with both lines of rails. Their irregularity indicates retardation, which is characteristic of rails of steam railways, due principally to the high resistance of the road ballast.

The electrical relations and actions between overhead wires and the rails are also strongly manifested during every thunderstorm in connection with overhead trolley railways, resulting in the frequent impairment of generators and car motors, notwithstanding the employment of lightning arresters and choke coils with such circuits. In fact so frequent are such actions manifested upon electric cars.

that their electric light circuits are turned on, so as to constantly maintain a continuous metallic path between the overhead trolley wire and the rails during thunderstorms and allow the flow of the induced electricity about the cars without constant sparking. This, however, can only be accomplished with safety to the car circuits when such induced electricity is of moderate intensity, attending distant discharges.

In Figure 25 is illustrated a trolley wire case described by Alexander Jay Wurts in a paper read at a meeting of the American Institute of Electrical Engineers, May 15, 1894, as follows: "A is a type



*Fig. 25.*

of strain-wire insulator, which is capable of withstanding from 15,000 to 20,000 volts. B shows a wire connecting an overhead return to the ground wire return. The distance between wire B and the iron loop holding the strain wire is about one inch. During a violent thunderstorm, the insulator A was punctured by a discharge which passed from the trolley wire through the insulator to the iron hoop and thence across the one inch air space to the grounded wire B, and this very high ohmic resistance path was taken in preference to a neighboring line arrester having a small air gap.

Had an arrester been connected at this point there is no question but that the arrester would have taken the discharge, but by reason of the nodal points which are formed along the line by the electric surgings, a lightning arrester 100 yards away, although it is liable to take a large proportion of the discharge, does not by any means offer an absolute guarantee of protection to a neighboring piece of apparatus.

A large number of line arresters, that is, a large number of opportunities for discharge, is the surest means of securing efficient protection."

The action of the opposite electricities of the air and earth in the case referred to was similar to those shown in Figures 21, 22 and 23 and also to the many cases where they have broken through brick and stone walls of buildings between ordinary lightning rods and the interior gas and water pipes of buildings, as previously mentioned.

They all indicate the main path or one of such paths of lightning discharges and completely refute the surging and nodal point theory, which is especially inapplicable to the case referred to in Figure 25.

In the case of ordinary telegraph lines, electric light or other circuits, having no adjacent long grounded conductors, the union of the opposite electricities is invariably effected at a series of points within a great distance resulting in the destruction of a number of insulators and wooden poles, unless properly protected.

I maintain that the proper protection of electrical circuits does not depend upon the hap-hazard employment of a number of lightning arresters, choke coils and fuses, but rather upon a correct system of protection, applicable to each kind of circuit.

### **Summary of Lightning Discharge Actions.**

It is quite evident that a great area of electricity both in the clouds and earth participate in each lightning discharge and that the equilibrium between them is effected by a series of discharges in quick succession in line with one or more points or areas.

The following is a summary of the principal actions attending such discharges.

First, Powerful electrical currents flow within a great area of earth toward the main path or paths of the electricity from the clouds, and they invariably select underground metal pipes and railway tracks, and overhead electrical conductors connected therewith or otherwise connected with the earth, for the reason that they offer the best conducting paths by which they can readily unite with that from the clouds.

Second, The electricity of the clouds invariably selects the vertical

metallic conductors, stone, brick or other spires, trees or other objects offering the best and shortest paths to underground pipes and railway tracks or electrical circuits connected therewith, or directly with the earth. It also selects telephone, electric light and other metallic circuits, long grounded telegraph wires, and wire fences, for the reason that they offer the best conducting paths by which it can readily unite with that of the earth at numerous points within a great distance.

Third, Simultaneously with a lightning discharge, there is also a series of induced electrical actions upon electrical circuits, railway tracks and similar long conductors varying in intensity according to the distance of the main discharge or discharges therefrom and the intensity of the latter.

Fourth, The induced electricity of large and especially long and adjacent metallic conductors flows at short intervals into each other, and all in the direction of the main path or paths of the electricity from the clouds.

Fifth, The opposite electricities between the clouds and the earth, also the electrical movements between adjacent electrical circuits or metallic conductors prefer short and the most direct paths possible.

Sixth, It is a well established fact that the electricity of the earth frequently manifests itself just before a lightning discharge takes place. The ringing of telephone bells and similar alternating effects upon electrical circuits, simultaneous with lightning discharges, are due to two actions. The induced electricity of an electrical circuit, as well as that of the earth, being nearest, is first manifested by its flow in the direction of the path or paths selected by the electricity from the clouds. As the latter approaches that of the earth and unites therewith, there is apparently a reaction causing a momentary flow upon such circuit in an opposite direction; there being an interval of time attending each union of the opposite electricities and such opposite electrical effects are repeated according to the number of successive discharges.

This is a more rational explanation of the cause of such effects than the oscillatory, see-sawing or indirect movement of the electricity between the clouds and the earth and similar attendant phenomena upon electrical circuits as suggested by Prof. Lodge.

Seventh, The galvanic current of a telegraph or other electrical circuit is opposed and counteracted by the successive electrical movements attending lightning discharges, thereby causing tapping of telegraph instruments, etc., along the entire circuit.

When of sufficient intensity such electrical movements destroy the insulation of the wire coils of relay magnets and cause fusion or damage of their contact points, and also damage of other electrical ap-

paratus. In connection with the opposed current of a dynamo, they frequently destroy the insulation of its armature and field magnets, also motors, lights and other devices employed with such electrical circuits.

When the simple electrical actions attending lightning discharges are considered, it is quite evident that the terms, nodal points, oscillations, self-induction, electro-kinetic momentum, electro-magnetic inertia, etc., as now employed, are inapplicable to such actions.

### **Improper Employment of Lightning Protection Devices.**

The protection of telegraph lines and apparatus from damage by lightning discharges received consideration as far back as 1846, when Prof. Joseph Henry suggested the application, at intervals, of a grounded wire to a telegraph pole and extended above its top to prevent the shattering of poles.

During the same year, Prof. C. A. Steinheil, of Munich, Germany, suggested a similar conductor in connection with a telegraph line with an air gap separating them and which is the basis of the ordinary lightning arrester system.

As now constructed lightning arresters consist of two or more carbon or metal plates or other forms of conductors, insulated from each other. One or more arresters are usually employed near the apparatus to be protected and are generally connected with a metal plate or bar imbedded or driven into the earth and in some cases surrounded by charcoal, coke or scrap iron, and when thus employed they are like the ordinary Franklin lightning rod.

Owing to the small area of the ground connection employed, the union of the opposite electricities of the clouds and earth is greatly retarded when a lightning discharge takes place in line with an electrical circuit and is invariably attended with destruction of electrical apparatus, poles, etc. Such an arrester path is only adapted for induced charges of low intensity flowing over a circuit simultaneous with distant lightning discharges.

The employment at intervals of lightning arresters and such ground connections along an electrical circuit, embodies the principle of the pole protection system shown in Figure 19, and the greater the number of such arrester or pole conductor paths, the greater is the induced electrification of an electrical circuit, as well as the attraction of the opposite electricities therefor.

While the union of the opposite electricities of the clouds and earth at numerous points within a great distance or area is necessary, especially in the rural districts, it can be safely accomplished without

employing an electrical circuit for that purpose which is the case with the present multiple arrester system.

A reduction of the induced electrification of an electrical circuit to a minimum is essential to effect the proper protection of its electrical apparatus and which can only be accomplished by a proper protection system.

Shortly after the introduction of the arc system of electric lighting the fusible wire was employed to protect telegraph, telephone and similar electrical apparatus from damage by the electric light and other powerful currents, when such circuits make contact with each other.

The destruction of such safety fuses invariably takes place during thunderstorms, and the electrical circuits are useless until the fuses are renewed.

For some years past I have carefully investigated the induced electrical actions and effects upon electrical circuits during thunderstorms and have found by practical tests that the ordinary method of employing lightning arresters increases the liability of destroying fuses and damaging electrical apparatus.

The choke or impedance coil is simply a circuitous or indirect metallic path and embodies the principle of the electrical experiment shown in Figure 7 and its success, as well as that of any arrester, depends principally upon the means employed for quickly discharging the induced electricity of an electric circuit simultaneous with a lightning discharge.

If the induced charge of an electrical circuit is intense and its discharge is greatly retarded, it acts like a retarded lightning discharge and will flow over choke coils and the electrical apparatus which is to be protected.

Lightning arresters, safety fuses and choke coils are employed with the various electrical circuits without regard to the different actions attending lightning discharges. They have erroneously been regarded as the principal requirements for the protection of such circuits, while the more essential ones have been overlooked.

Notwithstanding the failure of the present methods of protection, it has been fully demonstrated that electrical circuits can be properly protected from damage by the terrific lightning discharges and the attendant induced charges, commonly known as static discharges.

## **Development of Manual Block Signaling.**

Electricity was first employed in England, for reporting the arrival and departure of railway trains and for signaling purposes by means

of the needle and dial telegraph systems in which polarized or permanent magnets and reverse currents are employed.

In 1836, Mr. (now Sir) William F. Cooke, then a young Indian officer, while at Heidelberg, witnessed an experiment made by Prof. Muncke, with a needle telegraph apparatus, originally devised by Baron Schilling, of Cronstadt, in 1832.

He became greatly interested in the subject and later devoted his attention toward the development and introduction in England, of a practical system of telegraphy. For this purpose he formed an alliance in 1837 with Prof. Charles Wheatstone of King's College, London. At their suggestion the Great Western Railway in England began in December, 1839, telegraphing the arrival and departure of trains at stations between Paddington and West Drayton, a distance of about thirteen miles. From the outset this proved a success. They employed six copper wires insulated by a covering of hemp in an iron tube, laid six inches above the ground alongside the railway. In 1842 the wires were supported on poles by conical supports of earthenware, which was soon discarded for porcelain and glass. In 1844 Cooke installed a system of electric signaling on the Norwich and Yarmouth division of the Great Eastern Railway, a single line railway, divided into five sections. The system though simple in its mode of operation was cumbersome, as five circuits and five needle indicators were required at each station on the division, in order to make known the progress of the train.

Mr. Edwin Clark subsequently modified Mr. Cooke's method and introduced on the London & Northwestern Railway that mode of telegraphic signaling, known as the "Block" system; signifying the maintenance of a fixed minimum interval of space between two successive trains, travelling in the same direction on the same line. The railway was divided into blocks or sections, the length of which was governed by location and amount of traffic. The double needle instrument was employed with three circuits, two being devoted to the needle instrument, and one for bell or alarm purposes.

Each line, up or down, had its own indicating dial, arranged to represent three signals, viz., the needle inclined toward the left, "Train on line," toward the right, "Line clear" and vertical, "Line blocked," or "Instrument out of order." The two first named indications were maintained by constant currents of electricity; the third indication was the normal position of the needle when uninfluenced by the current.

In 1852 Mr. C. V. Walker, applied his electro-magnetic or single stroke bell for train signaling purposes on the South Eastern Railway, the signals being by sound only. During the same year, Mr. E.

Tyer produced his first block signaling instrument. This was provided with two needle indicators, combined with a treadle worked automatically, so that as each passing train depressed it, its approach was signaled to the station in advance, where the train on its arrival, by similar means, transmitted the "line clear" signal to the station in the rear. This automatic system after a short trial was modified by dispensing with the treadles and operating it by hand. The apparatus was also improved by employing magneto electricity in place of galvanic battery and a lock and key commutator, so designed as that a complete interchange of signals could be given only by the joint action of both signal men.

This system was gradually installed upon several railroads in England and Scotland.

In each railway signal station mounted levers are also employed connected with outdoor semaphore arms or disc signals, arranged so that the signalman can indicate danger or safety to the engineer of an approaching train. Normally these manual signals are placed in the danger indication. When a train approaches a station, such outdoor safety signal is given, if "line clear" is shown by the needle indicator and if "train on block" is indicated the outdoor signal remains at danger until the section ahead is indicated clear by the signalman at the other end of section.

Accidents have often been caused by the failure of signalmen to properly interpret such electric signals and to give the proper outdoor manual signals.

Quite a number of accidents have been caused during thunderstorms by the reversal of polarity and the demagnetization of the permanent magnets used in the apparatus. The signal "Line clear" has often been given by the action of induced electricity attending lightning discharges, even while a train was on a section of track. The following extract is taken from a work issued by Tyer & Norman, English Electrical Contractors, in reference to the use of permanent magnets upon railway signaling circuits after an experience of over twenty years upon many of the principal railways of Great Britain:

"Recently several attempts have been made to neutralize this reversal of signals from lightning by introducing into the instruments large permanent magnets, and therefrom inducing sufficient magnetism into the smaller magnets to actuate the indicator; but severe storms have shown the fallacy of trusting to any permanent magnet to overcome the effects of lightning, inasmuch as however large this permanent magnet may be made, to gain power, the force of the lightning is still greater; and when lightning protectors of extremely fine wire are employed in addition, these become fused, and the instru-



ment remains useless by the communication being thus stopped until proper means are taken to repair the damage." In order to secure immunity for their electric signaling apparatus from the induced electrical effects of lightning discharges, they were obliged to substitute ordinary electro magnets for permanent magnets and also to completely isolate the indicating portions thereof, excepting at the moment of the concurrent action of both signalmen, sending and receiving a signal.

In view of such annoying experience with polarized or permanent magnets upon railway signaling circuits in Great Britain and the Continent, the recent employment of such magnets with ordinary constant closed track circuits in this country will be followed with interest.

The simplest railway signaling system in use in this country is known as the telegraphic block system and consists of a series of towers or cabins, located at suitable intervals along a railway, in which is stationed a telegraph operator, who is in telegraphic communication with the operators at all other towers and also with the train dispatcher of the division. He also controls outdoor semaphore or other manual signals for the guidance of engineers. This system was first employed about 1865 on the New York and Philadelphia Division of the United Railroads of New Jersey, and is the most extensively used system, especially in connection with the single track roads of this country.

In 1875, W. R. Sykes, an English inventor, devised the system of block signaling known there as the "lock and block" system. In this the outdoor manual signal at a block station is controlled by the signalman in advance, by means of an electrically-operated lock connected with an electric circuit extending to the forward signal station of a block section. While each signalman operates his own signals, which usually control an up and down section, he cannot do so until they have been unlocked by the signalmen who are in advance.

In this and other manual systems used abroad and in this country, it is customary to employ a signal at the entrance of a block, to control trains in entering and using such block, which is known as the "home" signal, and another signal at a suitable distance in the rear of the home signal and operated in connection therewith, so as to regulate the approach thereto. This second signal is known as the "distant" signal. An advance or starting signal is one that is placed a suitable distance in advance of the home signal to provide a supplemental block between the home and such advance signal.

Upon several prominent roads, such as the New York Central and Hudson River and main line of New York, New Haven & Hart-

ford, an improved manual system, is employed, which is controlled by interlocking mechanism in connection with an electric circuit extending along each block section and operated by a locomotive or train at the forward end thereof.

About 1889, Messrs. Webb & Thompson of the London & North-western Railway introduced an electric train staff system which is a modification of the ordinary train staff system used in England for many years for preventing collisions on single track railroads. It is used to a limited extent in this country.

A full description of manual, interlocking and other block systems, employed in this country is given in "The Block System," by B. B. Adams, published by the *Railroad Gazette*.

### **Development of Automatic Block Signaling.**

The expense of maintaining the telegraphic block system and the failure to fully guard against accidents, together with the uncertainties attending the train dispatching system, led to the development of the automatic electric block system in this country.

Among the early inventors was Thomas S. Hall, of Connecticut, who installed the first automatic system in this country in 1871. It was a wire circuit system, and the normal position of each signal was safety. When a train reaches one of these signals, its wheels press a lever, closing an electric circuit and exhibiting a danger signal, and by a mechanical contrivance the circuit is kept closed and the danger signal displayed until the train reaches the next signal which is operated in the same manner. The movement of the second signal is made to open a separate wire circuit extending back to the first signal, releasing the latter and allowing it to assume its normal position.

The rear end collision at Revere Station on the Eastern Railroad (now a part of the Boston & Maine) upon the evening of August 26, 1871, between an express and accommodation passenger trains, killing twenty-nine and injuring fifty-seven, greatly stimulated invention and brought forth several automatic electric block systems.

F. L. Pope and S. C. Hendrickson in 1873 devised a wire circuit system with short insulated rail sections in connection with wheels and axles of locomotive or train, as circuit closers.

David Rousseau in 1875 developed a simple wire system with circuit closers operated by the deflection of rails.

All the wire systems referred to have since become obsolete, principally for the reason that safety signals were given by induced electricity during thunderstorms, crosses with telegraph wires and also when a detached portion of a train was on a block section.

During the winter of 1871-2, I commenced a series of experiments

of automatic block signaling circuits which continued until 1875. The first experiment consisted of a method of closing an electric circuit and energizing an electro-magnet by means of the tread of the wheels of a locomotive in connection with an insulated iron bar, parallel with a rail.

During June, 1872, the first automatic block system devised by me was tested upon the Lebanon Valley branch of the Philadelphia & Reading Railroad, in which the lever of a relay was operated by two electro-magnets in separate circuits and controlled an electro-magnetic visual signal in a local circuit.

When one electro-magnet was energized by a locomotive closing its circuit, near one end of block section, the lever of relay closed the local circuit and continued to display a danger signal until the last car of train passed off the block section at the opposite end, when the other electro-magnet was energized and the lever opened the local circuit restoring the visual signal to its normal position of safety.

The latter electro-magnet was connected by the two lines of rails of an insulated track section, about half a mile long, with a battery and circuit closer, at the opposite end of section. This was the first practical test of a track circuit in which the battery current was shunted from an electro-magnet by the wheels and axles of a train in connection with the rails of a track section. Quite a variety of rail circuit tests were made by me during the three years referred to, and one of the rail bonds then used, embodies the principle of the present bond used with such track circuits.

The shunting of the track battery current when a car on a siding projects too near the main track was also first suggested and patented by me, as well as the first track circuit embracing a simple overlap and the true normal danger principle. It is the germ of the ideal track circuit system and was then many years ahead of the times. The signal used was an enclosed disc of the banjo type and normally at danger with an open signal circuit.

During 1872, William Robinson, while experimenting upon the Philadelphia & Erie Railroad in Pennsylvania, invented the constant closed track circuit in which a galvanic battery is connected with the two lines of rails at one end of a track section and a relay magnet which controls a signal circuit, is connected with such rails at the opposite end of the section.

The Robinson constant closed track circuit system was tested upon several roads before it was practically employed in 1879 upon ten miles of the Fitchburg Railroad (now a part of the Boston & Maine).

A disc signal operated by clock-work under the control of an electro-magnet connected with a normally closed signal circuit was then

used. It was operated on the normal clear plan in which it always shows clear until a train enters a block section when it goes to danger and returns to safety when the train passes out of the forward end thereof.

Oscar Gassett of Boston, greatly aided the introduction of this system and also effected in 1879 the organization of the Union Electric Signal Company of Hartford, Conn., succeeded by the Union Switch & Signal Company, Pittsburg, Penn., which in 1881 controlled all track circuit patents and developed the electro-pneumatic system, which employs compressed air for the operation of the automatic signals. It is principally used upon the New York Division and part of the Pittsburg Division of the Pennsylvania Railroad and near the terminals of several other roads, where a large number of signals are required.

Efficient electric motors and economical primary batteries were then unknown and their development has made the electric semaphore possible within the past five years.

### **Automatic Electric Block Systems.**

Where traffic is heavy on double track roads and trains closely follow each other, it is customary to divide each track into sections varying from half a mile to two miles in length and prevent collisions by means of an automatic or manual block signaling system.

After an experience of over twenty years with the rails as the controlling electric conductors of automatic block signaling systems, the track circuit is now regarded as the best medium for preventing train collisions, for the reason that such circuit is under the control of every pair of wheels and axles of a train, locomotive or car, not only upon the main track, but also when upon sidings and projecting too near the main track. Broken or removed rails and open switches are also indicated by means of the track circuit.

The rail joints of each line of rails are bonded, usually with No. 8 galvanized iron wire soldered to iron rivets, which are driven tightly into quarter inch holes drilled in the flange or web of the rails. The two lines of rails of a track section are insulated from the rails of abutting sections by fibre about three-eighths inch thick.

The fish plates at these points are usually made of wood, bound with iron and the bolts are insulated with fibre.

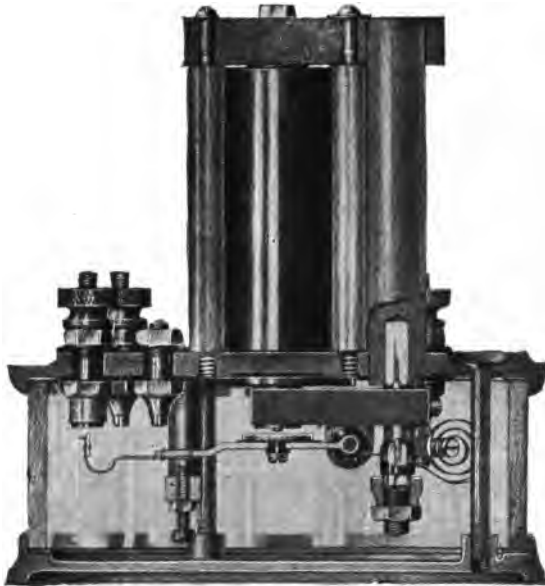
Such bonded lines of rails, usually about a mile long, are employed as the electric conductors between two gravity battery cells, in parallel, at the forward end of a block section and a relay at the rear end thereof.

When there is no train in the block, the current flows from the

positive pole of battery, thence through one line of rails and the wire coils of track relay, and by the other line of rails to the negative pole thereof, and constitutes what is known as the constant closed track circuit.

The electro magnet of the relay is thereby energized and causes its armature lever to close or open a wire circuit which is known as the signal circuit, and a safety visual signal to be displayed to an approaching engineer.

When the rails are bridged by the wheels and axles of a locomotive, train or car the battery current is thereby shunted from the wire



*From Electrical World and Engineer.*

*Fig. 26. Track Circuit Relay.*

coils of relay, thereby deenergizing the magnet and the armature lever closes or opens the signal circuit and causes a danger signal to be indicated.

The track relay is the most important feature of an automatic track circuit system. Ordinarily the wire coils have a resistance of about four ohms. Its armature lever and contact points are enclosed in a circular glass or dust proof box, the magnet coils and cores being placed in a vertical position on top of the box as shown in Figure 26.

The upper stop or stops with which the armature lever or levers of relay contact are platinum or carbon. The curved shape of the end of the armature lever makes it sufficiently elastic so that when it

is drawn up, its point slides on the surface of such stop making the connection self-cleaning.

The signal circuit or circuits under the control of the armature



*From Electrical World and Engineer.*

*Fig. 27. Home and Distant Signals Controlling Two Blocks Ahead.*

lever or levers vary in number, length and character according to the signal requirements.

Two forms of visual signals are employed for automatic signaling, the semaphore arm and the enclosed disc.

The semaphore arm is about  $4\frac{1}{2}$  feet long and 7 inches wide, placed at the top of a mast about 25 feet high, which stands near the track; the arm being upon the right of the mast, facing an approaching engineer.

When the arm is in the horizontal position it indicates "stop," or

"danger." When inclined at an angle of 45 degrees it indicates "clear," or "safety." At night the two positions are usually indicated by red (danger) and white (safety) lights respectively. A second arm on the mast about six feet below the top one, as shown in Figure 27, is now employed in the automatic block systems as a "caution" or "distant" signal of the next block section ahead. When this arm is in a horizontal position it indicates that the top arm or "home" signal upon the next signal post in advance is in the "stop" position, and that the engineer must be prepared to stop his train before reaching the next section, and when it is inclined it indicates that such "home" signal also indicates safety. At night the two positions of the second or distant signal are indicated by green and white lights. The end of the top or home signal semaphore arm is usually square, while that of the second or distant signal is forked.

The semaphore arms are usually operated by electric motors, compressed air or liquid gas under the control of electro-magnetism of the signal circuit.

Disc signals operated directly by electro-magnetism of the signal circuit are employed upon some roads and are the simplest in construction and operation.

They are enclosed in wooden cases to protect them from rain, wind, sleet, etc., and the only objection to them is the obscuration of the signals by damp snow clinging to the glass of the cases or by reflected light of the sun or sky upon the glass.

The first automatic track circuit system had no distant signals and to avoid the necessity of requiring trains to slacken speed at a signal (as in the case of fog) the "overlap" was adopted and is shown in Figure 28 as applied to one line of a double track road; the direction of trains being from bottom to top of the diagram.

The block section, A, C, is of the usual length of about a mile and its rails are employed in two separate circuits; the circuit A, B, or C, D, is about 1,000 feet long or sufficient for a train to stop therein when running at full speed.

When the signal at A is in the danger position, it indicates that a train is between B and D, and does not assume the clear position until after the train has passed D.

In Figure 29 is shown a system in which the home and distant signals (enclosed disc) are on same mast at the entrance of each block section. A, B, and B, C, represent two block sections.

The track relay of each section controls a signal circuit consisting of two line wires connecting a home signal with its distant signal.

The upper or home signal at A indicates the condition of section A, B, and the lower or distant signal the condition of section B, C.

By this system an engineer is informed as to the condition of two blocks ahead, and to be governed accordingly.

In the system shown in Figure 30 two signals (home and distant) are also employed at the entrance of each section A, B, and B, C, and the signal indications for two blocks ahead are given as shown in Figure 29, but without the employment of a wire signal circuit along the entire length of each section.

The relay connected with each track circuit has a neutral or ordinary armature lever and also a permanent magnet and a polarized arm-

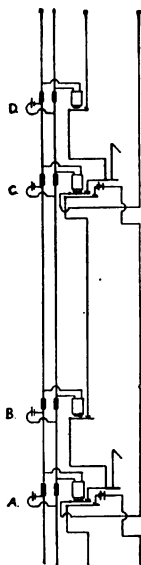


Fig. 28.

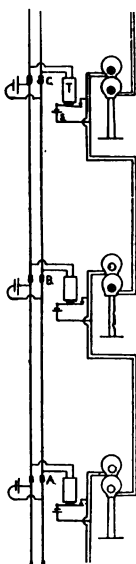
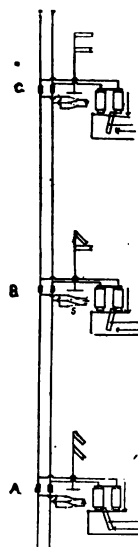


Fig. 29.



From *Electrical World and Engineer*.

Fig. 30.

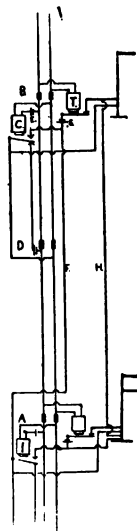


Fig. 31

*Track and Signal Circuits. Overlap Block, Fig. 28. Home and Distant Signals at Entrance of Each Block, Figs. 29, 30 and 31.*

ature lever, which control, respectively, the home and distant signals at the entrance of a block section.

Each home signal is fitted with a pole changing device, which, as the signal moves to danger, changes the direction of the current in the track circuit preceding it and causes the polarized armature lever of the relay at the other end of circuit to shift and open the circuit of the distant signal there located, whereupon this signal assumes the caution position.

This system is known as the "wireless" and is of recent development. Its signal circuits are short, and therefore, can be prevented from being deranged by sleet and wind storms, which is the principal object of this system.



The three systems described are known as the "normal clear," in which the signals normally indicate clear or safety.

In Figure 31 is shown a system in which the home signal stands in the stop or danger position until a train approaches it, when, if the block ahead is clear, the signal will assume the clear position until the locomotive has passed it.

The signal circuit at B embraces the armature lever of track relay, T, signal battery, S, and also armature lever of relay, C, which is known as the clearing relay and is controlled by track battery, E.

When a train passes D, the signal circuit of B is closed by the armature lever of relay, C, when, if the block ahead is clear, the armature lever of relay, T, will complete the circuit through the signal at B and cause it to indicate clear or safety.

As the train passes D the home signal at A is still held in the danger position by the armature lever of relay C, which holds the track battery at D open until the train has passed entirely out of the block at B. Line wires F and H, signal battery, S, armature lever of relay T, and armature lever of clearing relay I control the distant or caution signal at A and will indicate clear when a train approaches if the block ahead of B is clear.

Several other arrangements of track and signal circuits for double and signal track roads are used.

Since the employment of the automatic systems described and referred to, train collisions have been greatly reduced and a great saving of time effected in the movement of trains, and they are deemed as safe as the simple manual and controlled manual systems, by both of which errors have been made, resulting in collisions. Even with the most improved mechanical appliances signalmen will occasionally blunder.

### **Locomotive Cab Signaling.**

Railway accidents happen occasionally in spite of the tracks being protected by automatic or other block signals, due to the visual signals being obscured by fog, snow, smoke, etc.

On the morning of January 8, 1902, a New York, New Haven & Hartford suburban train was stopped by signal in the Park avenue tunnel, New York City, and one minute later a New York Central train of the Harlem Division, collided with the stopped train, plowing through the hind car, killing seventeen persons and injuring many others.

Thick snow was falling at the time of the accident, the atmosphere was heavy and the smoke and steam consequently so low that the engineer of the colliding train could not see the signals in the tunnel.

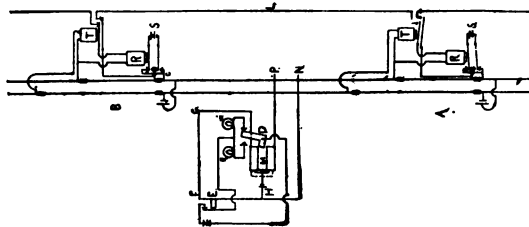
To guard against such accidents a number of systems have been devised during the past twenty years for automatically giving electric signals upon a locomotive while in motion, or electrically controlling its whistle, emergency brakes, etc.

The Park avenue tunnel accident has stimulated invention in cab signaling and a favorite method among inventors at present is the electric intercommunication or signaling between trains by means of insulated sectional conductors along a railway.

Inventors, as a rule, are not aware of the fact that too much intricacy in signal circuits and signals, is liable to impair or render them inoperative at a critical time and lead to disaster.

Nearly all the cab systems suggested are very complicated and are not adapted for safe signaling.

In Figure 32 is shown an automatic cab signal system under the



*From Electrical World and Engineer.*

*Fig. 32.*

control of track circuits, which has been tested upon the Chicago & Eastern Illinois Railroad during the past three years, in which two small incandescent lamps (one white or safety indication and the other red or danger indication) are employed in the cab of a locomotive.

In this system insulated track sections with batteries and relays are employed in the usual constant closed circuits, and at the near end of each regular track section is an adjacent short insulated track section, which connects with the locomotive signal control circuit.

The locomotive equipment and circuits are shown at lower part of the diagram and consist of incandescent lamps, R and W, in a signal circuit under the control of the armature levers of ordinary relay, E, and polarized relay, M, which are in a partial circuit, terminating in the wheels of a locomotive at P and the wheels of one of the tender trucks at N, which are insulated from the tender.

When there is no train between A and B, the track relay T at A is energized and its armature lever closes a combined wire and rail circuit, consisting of battery S and an armature lever of relay R at B, one line of rails between C and A of the regular track section, relay R

and an armature lever of relay T at A, line wire, L, and an armature lever of relay T at B.

If a train is in the block section, the track battery is shunted by the wheels and axles from relay T at A, thereby causing the combined wire and rail circuit to be opened and deenergizing relay R at A. As soon as the wheels P of the locomotive approaching B, passes, the first insulated joint near C the locomotive control circuit forms a bridge over that joint and then current of battery S at B flows over it in one direction, if relay R is energized at B, causing the polarized armature of magnet M upon locomotive to close the signal circuit through the white lamp. If the relay R at B is deenergized, the circuit from battery S will pass through the magnet M in the opposite direction and close the signal circuit through the red lamp.

The indication thus received, when passing a signal station, will be carried to the next block station; thus, if the signals are thrown to danger upon passing the block station A, the red light will continue until the station B is reached, where it will remain at danger or go to safety according to the conditions ahead. In case no indication either by red or white light is received in the engineer's cab, it is, of course, taken for granted that there is a danger signal and the engineer proceeds just as if a positive red-light danger signal had been received.

The object of the battery H is to guard against a break in the locomotive control circuit. Under normal conditions the circuit from this battery divides, part going by F and G and part by way of N, the rail and P. These two circuits neutralize each other in the magnet M, so that the polarized armature remains wherever it was placed at the last station passed. In case the circuit through the track is broken, the current from H goes through the top half of the magnet M, which is so wound that the armature closes the circuit through the red lamp. If the circuit through F and G is broken, the relay E allows the lamp circuit to open and neither lamp burns. While the circuit from the battery S must go through the one cell at H, this cell does not interfere with the signal battery, merely working with it in one case and neutralizing a part of it in the other. It will be noticed that a train in any block reverses not only the battery of the first block station in its rear, but also that of the second station in the rear through the line wire.

While the efforts of genius to provide means for the safe movement of trains are praiseworthy, it must not be forgotten that the surest safeguards against accidents consist in the simplicity of a signal system, so devised that an engineer cannot be misled by improper signal due to defective mechanism, residual magnetism or other cause. The impairment of the circuits by the elements and atmospheric electrical disturbance must also be considered and prevented.

## Mileage of Block Signal Systems.

The following statistics of block signal systems employed January, 1902, on the principal railroads in the United States have been compiled from the *Railroad Gazette* and report of the Committee on Safety Appliances of the American Railway Association.

### TELEGRAPH BLOCK SYSTEM.

Number of railroads .....	48
Miles of single track .....	17,860
Miles of double track .....	5,405
Miles of four track .....	105
Miles of road .....	23,370
Miles of track .....	29,090

### AUTOMATIC ELECTRIC BLOCK SYSTEMS.

Number of railroads .....	38
Miles of single track .....	444
Miles of double track .....	2,673
Miles of four track .....	224
Miles of six track .....	5
Miles of eight track .....	4
Miles of road .....	3,350
Miles of track .....	6,748

### AUTOMATIC SIGNALS OPERATED BY COMPRESSED AIR.

Number of railroads .....	8
Miles of track .....	901
Number of semaphore signals .....	2,509
Number of disc signals .....	41

### AUTOMATIC SIGNALS OPERATED BY BATTERIES, ELECTRIC MOTOR AND CLOCK-WORK.

Number of railroads .....	37
Miles of track .....	*5,847
Number of semaphore signals .....	2,229
Number of disc signals .....	4,808

The automatic systems are principally employed on the following railroads, Pennsylvania, Philadelphia & Reading, Lehigh Valley, Central Railroad of New Jersey, Delaware, Lackawanna & Western, branch roads of New York, New Haven & Hartford, Harlem Division of New York Central, Boston & Albany, Boston & Maine, Michigan Central, Illinois Central, Chicago & Northwestern and Cincinnati, New Orleans and Texas Pacific.

### CONTROLLED MANUAL SYSTEMS.

Number of railroads .....	10
Miles of single track .....	246
Miles of double track .....	418
Miles of four track .....	376
Miles of road .....	1,040
Miles of track .....	2,586

The controlled manual systems are principally employed on the main lines of the New York Central & Hudson River, New York, New Haven & Hartford, Erie and Chesapeake & Ohio railroads.

### ELECTRIC TRAIN STAFF.

Number of railroads .....	4
Miles of single track .....	38

\*2,090 miles of track were equipped during 1901.

## Perfect Railway Signaling.

There were, in January, 1902, about 28,000 miles of railroad and 38,500 miles of track in this country operated by the different block systems, while ten years ago there was only about one-tenth such mileage.

The introduction of the automatic system with track circuit during the fifteen years, 1880-1894, was slow. In fact, it was only after the simplification of the semaphore and disc signals that such system attracted the attention of railroad managers.

While its signal apparatus has been simplified, the track and signal circuits, owing to the requirements of railway traffic, have become very complicated, and to such an extent that they are easily deranged during thunderstorms and are otherwise objectionable.

The simple constant closed track circuit of 1879 was soon superseded by the overlap or complicated system, requiring the two independent track circuits, shown in Figure 28. This was followed by the employment of home and distant signals in the long signal circuit shown in Figure 29, and later on by the present normal danger system shown in Figure 31, which employs a long signal circuit in connection with two independent track circuits. In some of the more recent constant track circuit systems devised, there are many objectionable complications, and they are easily deranged.

In hilly sections, the cold wave during a thunderstorm advances over the low ground and water-course or courses in a valley, especially those located east and west, raising the moist warm air; and the width of the storm conforms to the breadth of the valley, and when it divides by flowing through two or more valleys, more or less parallel to each other, then there are that many storms abreast of each other with the mountain ridges between them. There is invariably a great generation of atmospheric electricity over such a valley, attended with a great induced electrification of the water course or courses, low ground and subterranean water-bed.

Railway track circuits, together with their signal circuits in such valleys and also in open rural sections, especially where the water-bed is not at a great depth, become intensely electrified and offer the best paths for the opposite electricities of the clouds and earth to readily unite by lightning discharges. The overhead telegraph wires along a railroad are also inductively electrified, and are utilized to a certain extent for such electrical union.

For the protection of the track and signal circuits, fuses and arresters connected with the ground in the usual unscientific manner are employed therewith, and have proven a failure.

This is not at all surprising when it is considered that at the time of each lightning discharge between the clouds and the earth, the induced electricity of a number of adjacent track and signal circuits must participate in the restoration of the disturbed electrical equilibrium, and for lack of suitable conducting means, such induced electricity is greatly retarded in each of the circuits, and causes the destruction of fuses, fusion or damage of relay contact points, and also the impairment of relay and signal magnets and signal circuit cables.

The flow of induced electricity between the rails and earth, and vice versa, is also retarded by the rock, broken stone, cinder or other material of poor conductivity, constituting the road-bed, and especially is this the case at the beginning of a storm, before a heavy rainfall.

The following extracts are taken from a report issued during 1900 by a committee of the Railway Signaling Club on automatic block signal failures due to lightning, and which gives the experience of fifteen railroads of this country, having a large or moderate track mileage of automatic signals:

"It will be noticed that lightning affects signal circuits under nearly all topographical conditions. In almost all cases, lightning has been most severe in localities where there are flowing streams or large bodies of water, especially where trees grow along the shores. In mountainous regions there appears to be more trouble on the slopes than at the apex. Ravines and valleys are also affected where air currents converge. It is also more noticeable in mineral districts."

"Relative to the use of arresters and fuses, the replies indicate that there is very little difference in the amount of damage done to relay points and magnets, whether arresters or fuses are used or not."

"Platinum relay points appear to have been more readily fused than other contacts, the number of such cases being in excess of the total cases reported."

"The use of cables for signal controlling circuits, instead of placing wires on pole line, is not considered favorable; for the reason that there is much unnecessary trouble arising on all circuits in the cable, if there is a puncture by a discharge of lightning."

I am informed that along a certain railroad running east and west from 75 to 100 fuses are destroyed during each severe thunderstorm, which means the derangement of the signal circuits until the destroyed fuses are replaced. Such damage and derangement will continue until properly arranged track and signal circuits and a proper system of lightning protection are employed.

The proper requirements for the protection of track and signal circuits have been determined after a thorough investigation of the induced electrical actions attending them during thunderstorms.

The electric circuits employed in connection with the controlled manual and simple manual systems are also deranged during thunderstorms.

The simplification of the automatic signal apparatus has been attended with a reduction in the number of improper safety signals, which is regarded as the most dangerous error of an automatic or any signaling system.

The fusion of the contact points of the track relays during thunderstorms will cause false safety signals to be given.

The most careful treatment of relay and signal magnet cores and armatures cannot entirely remove the tendency of iron, when magnetised, to retain a small portion of its residual magnetism, which is another cause of false clear indications. Some constant closed circuits will soon develop residual magnetism.

In order to prevent a safety signal being given by such fusion of relay contact points and residual magnetism of the relay magnets, a device has been attached to the sensitive armature lever of the track relay for the purpose of shunting the battery current from the signal magnet. I maintain that it is undesirable and not required in an absolute normal danger system.

Notwithstanding all the precautions that can be taken there is still a possibility of a false safety signal being given by any of the present automatic systems. In fact, no semaphore or disc system is ever likely to be devised that cannot give a false clear indication.

A number of railroad managers still favor the manual system and contend that an automatic system open to the possibility of giving a false clear signal is hazardous, while with the manual system they claim that there is a likelihood that an improper clear indication, given by defective mechanism, sleet, etc., will be detected in time by a signalman and a disaster averted. The impairment of the automatic systems and the consequent delay of trains attending thunderstorms is also objectionable.

That there is room for considerable improvement in automatic block signaling is a fact well known to railway managers and signal engineers.

Automatic signaling has been undergoing the same experience as many other important inventions, which after passing through the complicated stages, have finally been reduced to simplicity, reliability and the greatest efficiency.

It is our aim to introduce simple and reliable automatic systems which will fully overcome all objections existing against automatic signaling, and also meet the railway requirements.

They are the first practical systems which embody the *absolute*

*normal danger plan*, by which an engineer can *positively* determine when a safety signal is improperly given, and therefore cannot be misled by such a false signal.

They are the only systems which fully conform with the established practice governing train order and manual block signals, which are required to stand normally at danger for the reason that it has been found unsafe to operate them on the normally clear plan. The improved automatic signals are at all times at danger except when cleared by an approaching train, which can be done only when the block section is clear.

The circuits of the improved systems are arranged upon true scientific lines, and will not be impaired by induced electricity during a thunderstorm. The fusion of relay contact points and impairment of the relay and signal magnets are prevented.

The great importance of proper lightning protection is becoming more apparent every year. As shown by the report of the Railway Signaling Club, the signal circuit cables as now employed are impaired during thunderstorms. They are essential for preventing wire crosses and derangement of signal circuits during sleet, and other storms. A few more sleet storms like the destructive one between New York and Baltimore last winter, when all telegraphic communication between those points was suspended for several days, will eventually be followed by the placing of signal circuits and train dispatching wires in conduits along the sleet sections of the principal railroads. Attention is called to the fact that a number of underground electric cables are annually impaired by induced electricity during thunderstorms, especially in the rural districts, owing to the hap-hazard method of such installations.

In the improved systems the possibility of residual magnetism in the signal and relay magnet cores and armatures is reduced to a minimum, which necessarily implies that there is also a comparatively small consumption of battery power.

An important improvement is a novel method by which the rails can be properly employed for a longer track circuit than has heretofore been possible. As is well known, a portion of the track battery current is shunted by the ties and ballast, especially during wet weather and while well moist, which limits the use of the rails for a single track circuit to about a mile and less, according to the character of ballast, and presence of sand, etc. This improvement also paves the way for simple locomotive cab signaling upon the absolute normal danger plan, in connection with a track circuit.

The improved absolute normal danger systems with their varied features are novel: they will be fully and broadly covered by patents.



All other inventors have apparently been confining themselves to the ordinary constant closed track circuit or strictly normal clear plan, which experience and established railway practice have fully proven to be unsafe for railway signaling.

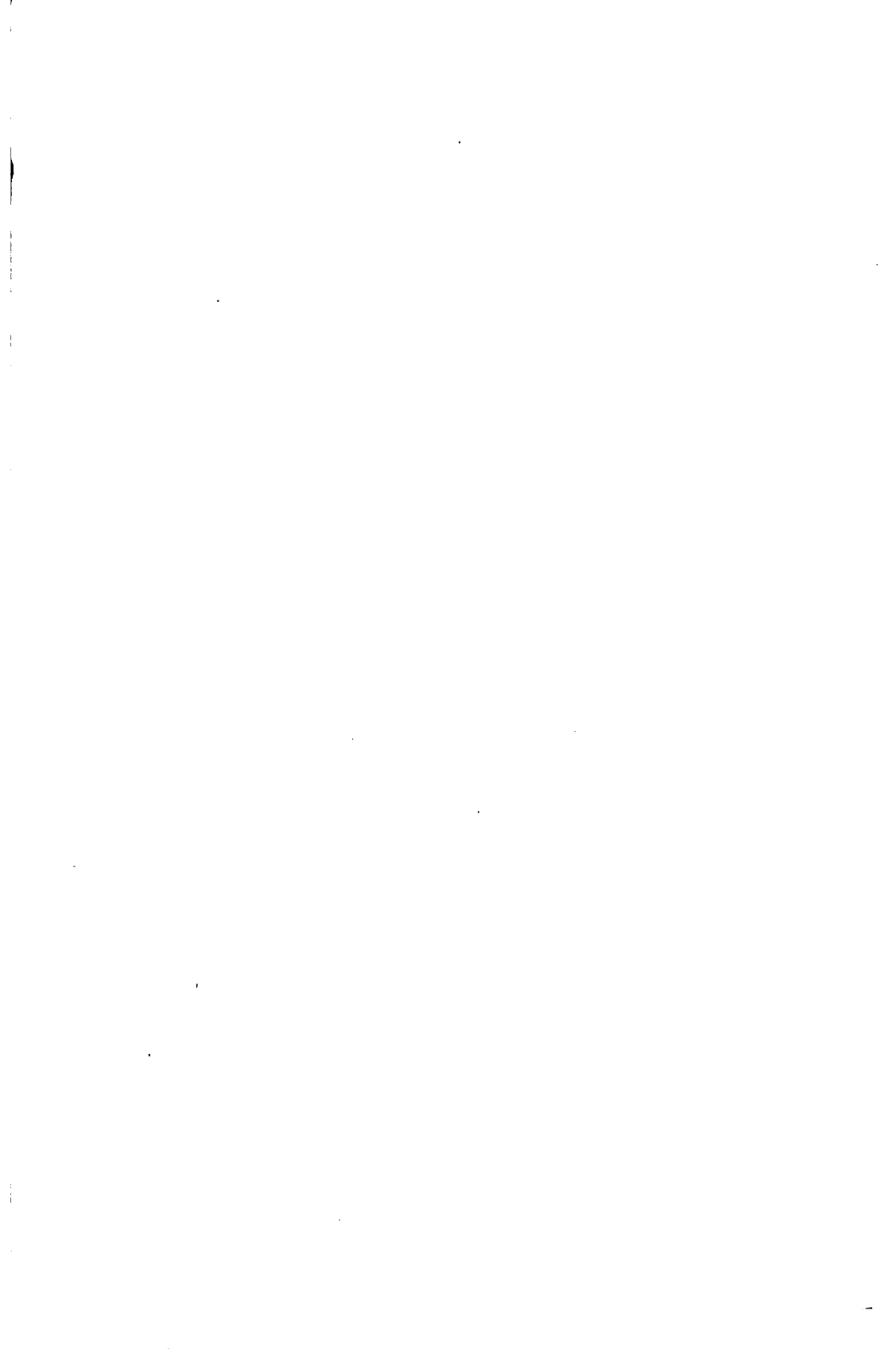
For obvious reasons, a description of the improved signaling systems is withheld for the present. It will be forthcoming in due time.

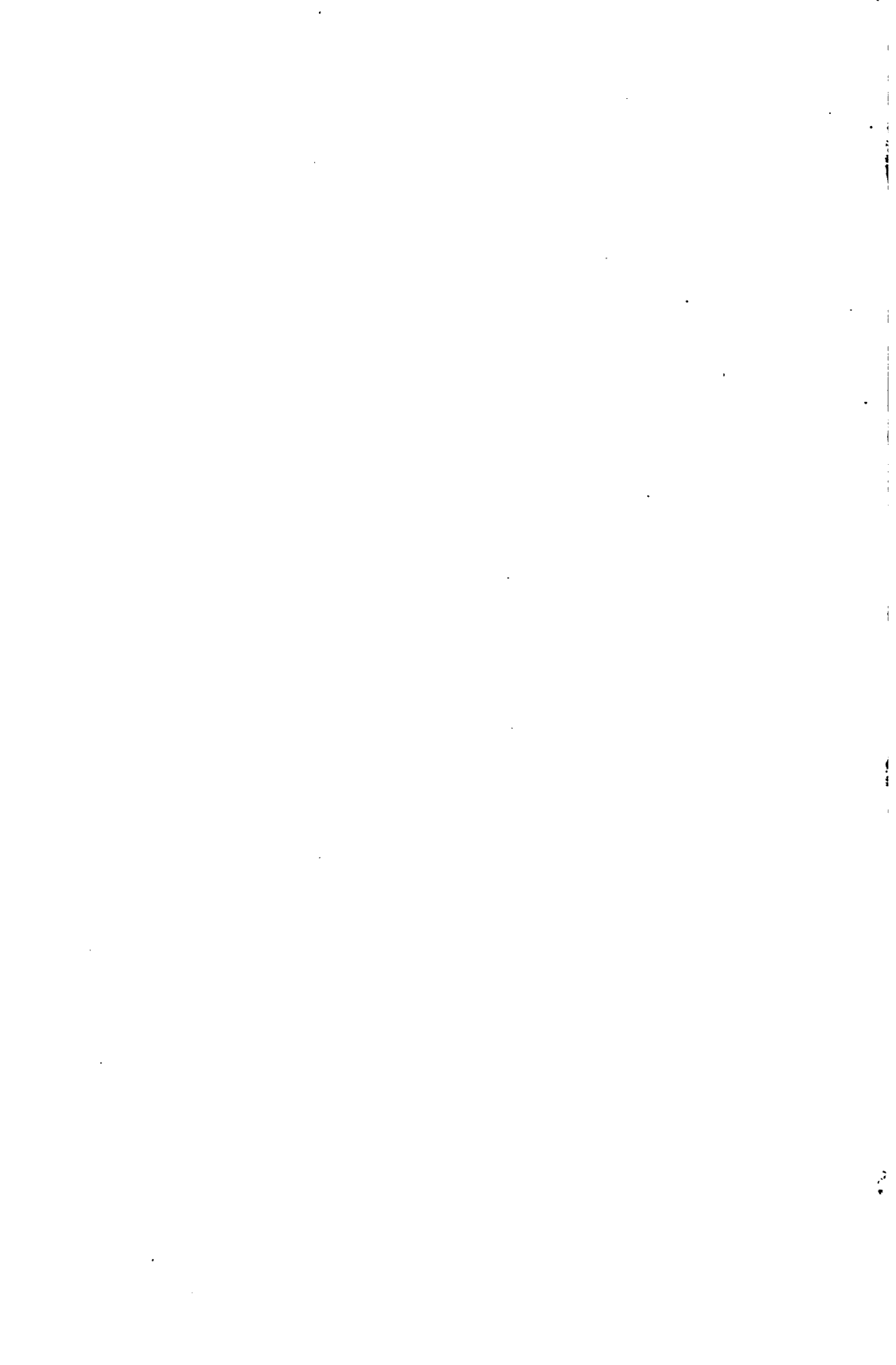
The improved systems can be applied to railroads now using track circuit systems, and some of the improvements can even be employed to increase the efficiency of the existing systems.

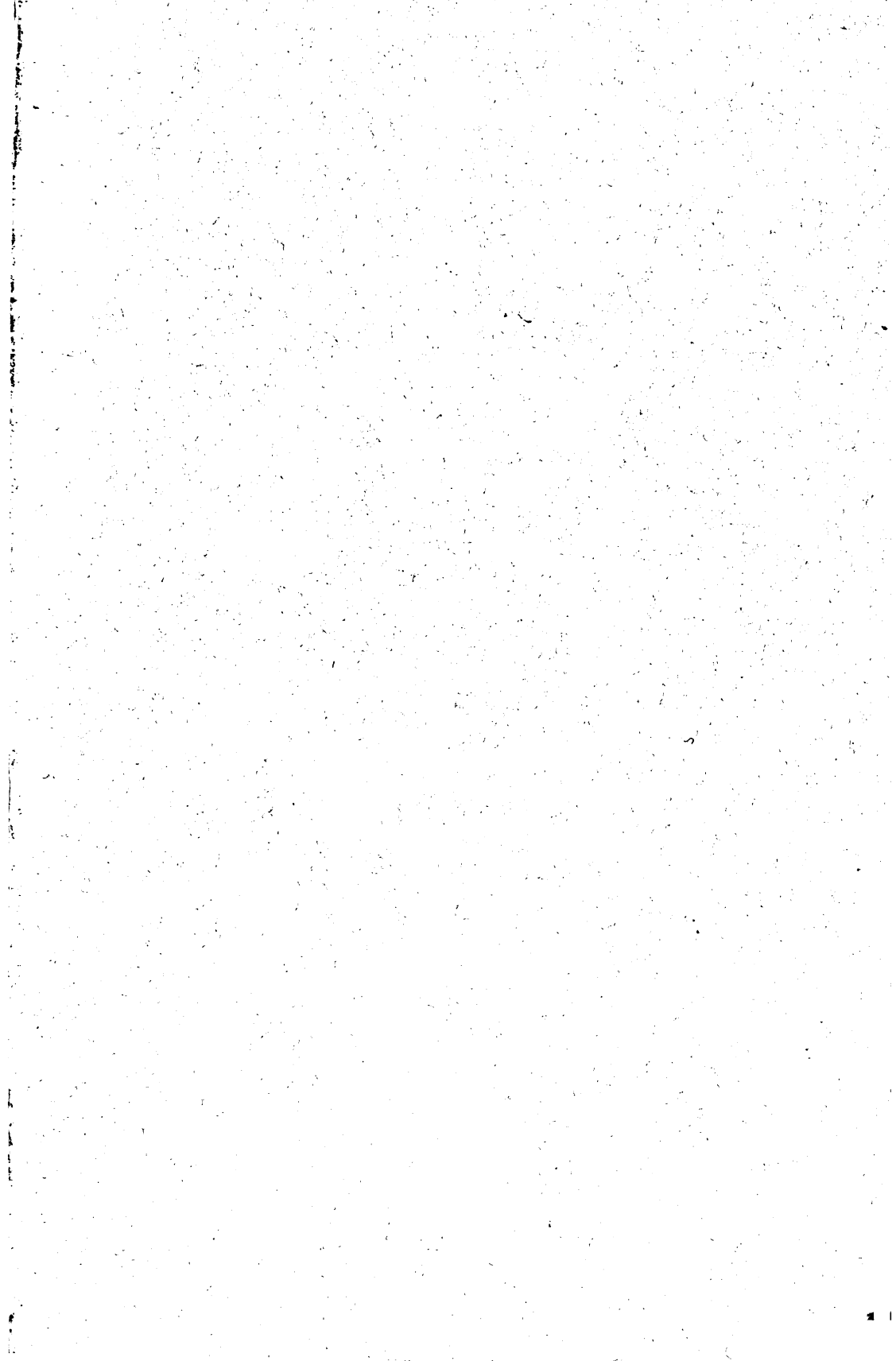
It is evident that any radical improvement which tends to increase the simplicity, efficiency and reliability of automatic signaling will make it possible to equip many more miles of track with such signals, than would otherwise be protected. The increased safety afforded, as well as the small expense of maintaining the improved automatic signaling systems as compared with any manual system which requires the constant attendance of a man at each end of a block section, greatly favors the general introduction of the perfect railway signaling.

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